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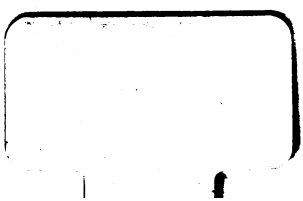

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THE

CHEMISTRY OF COMBUSTION,

APPLIED TO

THE ECONOMY OF FUEL

WITH SPECIAL REFERENCE TO

THE CONSTRUCTION OF FIRE CHAMBERS,

FOR

STEAM BOILERS.

BY

E. W. DIMOND.

The Empire of Man over material things has for its only foundation the Sciences and Arts — Bacon.

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TO

SIDNEY SMITH,

AND

THOSE ASSOCIATED WITH HIM

IN ENDEAVORING

TO SECURE GREATER ECONOMY OF MEANS,

BY WHICH THE VAST AND DIVERSIFIED INDUSTRIAL PURSUITS

OF MANKIND MAY BE PROMOTED,

THIS VOLUME

IS RESPECTFULLY DEDICATED,

BY THE

AUTHOR.

"In a Manufacturing Nation, the application of scientific results to the arts, should be the prime object of every employer of skilled labor, who would not be left behind in the race of improvement."

PREFACE.

It is the object of the present volume to give to those, who desire useful and practical information, an outline of the leading principles and main facts of this particular branch of chemical science, in language as simple and definite as possible. The aim has been to rise to the level of the more important and difficult questions, from a basis so elementary as to bring them within the comprehension of all persons possessing any imaginative faculty and power of concentration.

The value of science to the industrial operations of the age, and to the past and present progress of civilization, is too widely known and generally accepted to admit of question, and while Chemistry, as a branch of systematized knowledge, is one of the latest which has offered its services to man, yet, during its short existence as a separate science, none has, in a greater degree, increased human resources and comforts.

Glance over a work on Technology, and it becomes at once evident that there is now scarcely a process in the mechanic arts, over some part of which chemical laws do not preside. The manufacture of steel, glass, and porcelain, the economical reduction of tin, silver, copper, lead and zinc from thier ores, are strictly chemical processes; while bleaching, dyeing, calico-printing, sugar-refining, gas-making, the manufacture of gunpowder, friction matches, as well as photography, lithography, etc., are boons of chemical science which bespeak its value to those engaged in manufacturing industry.

Modern Chemistry possesses peculiar attractions, from the fact that it is an *experimental* science, for it does not in the present, as in past centuries, consist of the fanciful dreams, wild speculations and gross absurdities of Alchemists and Magicians. It is now the result of a rigid inquiry into Nature's processes, by the aid of those proofs and illustrations

which Nature herself furnishes. It recognizes no man's opinion or dictum, unless sustained by experimental tests from the crucible, the retort and the balance. It has reached a point where its principles can be presented with mathematical precision, while the brilliancy of its phenomena, the beauty of its philosophy, and the economy of its wonderful processes can hardly fail to awaken the attention of any intelligent being.

Technical terms always present a formidable obstacle to practical men in the investigation of any scientific subject. This serious difficulty we have overcome as far as possible. The use of chemical symbols has been studiously avoided, and at the end of the work may be found a Glossary, containing an explanation of such technical words as the nature of the subject has rendered it impossible to exclude.

As only a few weeks have been devoted to the preparation of these pages, many errors and imperfections will doubtless appear to those more proficient in scientific learning, but it is of comparatively little moment what opinion mere critics may form of these efforts, provided they present such an enlightened view of the subject as will correct false notions, remove uncertainties, and lead to the application of such principles as will in any degree arrest the prodigal and improvident use of one of Nature's richest gifts to man.

WORCESTER, MASS.,
Jan. 1st. 1867.

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INTRODUCTION.

THE present age is characterized by an unprecedented development of science and art. Mankind have hardly ceased to look with amazement upon one grand discovery before others still more marvelous are evolved in rapid succession. Every newly discovered truth in physics furnishes a key, which unlocks a world of wonders and opens a rich and boundless field for inventive genius. New arts are multiplying by the thousand, and the triumphs of practical skill are teaching conceited philosophers and high bred schoolmen the folly of longer hugging the fond delusion that only "the stupid hodmen of humanity" stand at the plough, the loom and the anvil.

Machinery now governs the world, though it was but yesterday that its improvements and achievements were deemed worthy of a record. History may now, without a sacrifice of its dignity, venture to chronicle the discoveries of a Watt, a Fulton, a Daguerre or a Morse; for if any class can be said to hold in their hands the future destinies of the race, it must be those skilful inventors whose genius is changing the whole aspect and condition of the civilized world.

Man, even amid the smiles and bounty of Eden, was commanded by his Maker "to subdue the earth," an injunction

which implied that he was to live by his labor and ingenuity. Every living being was ordained to preserve life and secure enjoyment by the diligent employment of those organs and faculties adapted to the theatre of its existence. Happiness can be realized only as a reward of effort. It is contrary alike to philosophy and experience to suppose that man could have been disciplined for the work assigned him, had not his energies been incited to action by privation. Without the stimulus of want the arts would have been unknown; without *these* the principles of science must have remained undiscovered, and a refined and enlightened civilization impossible. Inclemency of seasons, sterility of soil, scarcity of food and hidden treasures are God's incentives to urge man to observe, reflect, invent and construct, thus opening the way for unfolding the higher faculties of his nature.

Inventions and civilization are coeval. Open the pages of man's biography wherever we will, and we find him at first an untutored savage, using no force but his own muscular power. Hunger urges him to seek food. He has neither claws for catching, nor teeth for killing his prey. He seizes a club, while a stick serves for a knife. Soon game becomes scarce; he is forced to cultivate the soil, and is thus led to contrive the necessary implements, though, at first, his plough is but a sharpened stick, and his sickle a shell. He can no longer lead a wandering life. Primitive manufactures spring up. The social faculties of his nature begin to develop, and the value of labor is felt. But human strength is soon exhausted, and he is forced to reflection. He sees animals around him stronger than himself. He invents a rude yoke and presses them into his service.

His progress is now more rapid. He begins to invent machinery. Motive power is wanted; goats, dogs and bears

are trained to climb in tread-mills. The first requisite for a good motive power, however, is *constancy*. This, by reason of sickness, accident, and time required for rest, cannot be found in vital forces. At length he perceives the momentum of water in rapids and cascades. He arranges a few rough boards around an axle. This rude piece of mechanism suspended between two boats in a rapid stream gives us the water-wheel. He now begins to comprehend that nature designed him to use his intellect in bringing the forces of *unconscious* matter under his control. He arrests the murmuring breeze, and compels even the furious gale to pause and become the driver of machinery. But wind, as a motive power is irregular and uncertain, and water can be used only where a natural fall is available. He, at last, discovers, beneath the dancing lid of a tea kettle, a power which is to advance civilization with a rapidity never anticipated in the wildest dreams of philosophers and statesmen of former generations.

The mightiest agent yet discovered by man, in enabling him to fulfil his destiny in subduing the earth, is Heat through Steam, "that unwearied drudge of all work, which grinds our corn, weaves our clothing, forges our tools, drives our printing presses, twists a massive cable of iron, or spins a gossamer thread of cotton, impels our steamships on their ocean routes, defying wind and wave, or whirls us through space when we journey on land, with thrice the speed of a race horse. Nothing furnishes man with greater cause for congratulation and even an excusable pride, than the feats of that mighty impersonation of brute force and human intellect, the Steam Engine, the Hercules of the nineteenth century, which once launched into the world's arena has gone forth 'conquering and to conquer,' fulfilling

its high destiny as a civilizing agent, with an energy which no human arm can arrest, and a rapidity which fills us with astonishment, admiration and hope. For all these achievements man is indebted to laws which govern the combination of the electro-positive elements, carbon and hydrogen, found in fuel, with the oxygen of the air." Fuel, then, is to the steam engine what the main-spring is to a watch, the source of its power and the measure of its effects. Indeed, fuel may be regarded as the main-spring of modern civilization, for there is scarcely a process in the mechanical arts, in which heat obtained from its combustion is not a prime agent. "Civilization," says Baron Liebig, "is the economy of power." Fuel is the power of civilized nations, and hence, any step towards securing greater economy in its use, is a step towards advancing the arts pertaining to civilization. It requires but little reflection indeed to see that this subject has not received that searching examination and scientific consideration which its magnitude and importance demand. Acute intellects have, for nearly a century, been employed in perfecting the *engine* and the *boiler*. Within this time the efficiency of these has been increased more than ten-fold, and further improvements are still in progress, while the present method of effecting the combustion of fuel in the fire chamber shows but little improvement since the days of Watt. It is stated by good authority,[1] that the work done by fuel, in a good engine of the present day, does not exceed one-sixth part of what the coal is capable of doing. In furnaces, too, the portion of heat actually used is a small fraction of the heat wasted; and in the domestic use of coal, in open grates, at least four-fifths of the heat escapes up the chimney. Such facts as these are a re-

[1] Jevons on the Coal Question.

proach to the advanced state of physical and chemical science enjoyed by the present generation, and should admonish us to make a searching and sifting investigation of the subject with a view to economization. Fuel, as a prime agent—as one of the mightiest of visible motors which a bountiful Providence has placed at our disposal, is too precious a gift to be carelessly squandered under the constantly increasing requirements of civilization. "When Ho-ti's house, containing a litter of young pigs, was burned to the ground, it was natural that he should discover the delicate taste of roasted pig; and it was equally natural, as a consequence of this discovery, that the inhabitants of Pekin should introduce pigs into their houses, and burn them down, when they desired to participate in a dish so savoury; but it was a *great discovery* when *a very ingenious person* found that a common fire would do equally well, and that it was not absolutely necessary to burn down a house every time a pig was to be dressed." We may not be quite so prodigal as these curious personages of Chinese History, but reliable investigations respecting the smelting of iron have elicited the astonishing fact that, in spite of the saving obtained by the introduction of the hot blast, no less than 80 per cent. of fuel is wasted, only 20 per cent. being utilized. That "*very ingenious person*" who can discover and bring into general use some method of reducing this enormous waste of fuel in the working of furnaces, marine, locomotive and stationary engines, and in the various other processes in which heat is an indispensable agent, will receive the grateful homage of the present and future generations.

PART I.

SUBSTANCES EMPLOYED AND PRINCIPLES INVOLVED IN THE PROCESS OF COMBUSTION.

CHAPTER I.

Nature and Sources of Heat.

Heat, like all other physical agents, is known and measured only by its effects upon matter.

Sensible Heat.—One of the most familiar of these effects is the sensation of warmth or coldness which a body, when it receives or parts with heat, produces upon our organism. When the heat received or lost by a body is attended with the sensation of warmth or coldness, it is called *sensible heat.*

Latent Heat.—It often occurs that a body may receive a very large accession of heat, without any sensation of warmth being produced by it, and may, on the other hand, lose a considerable quantity of heat, without exciting a diminished sensation of warmth. The heat which a body would thus receive or lose, without affecting our senses, is called *concealed* or *latent heat.* The heat of a fire, for example, would be called *sensible,* the heat in ice, *latent.*

Various theories have been propounded respecting the nature and cause of heat, none of which have fully explained *all* the phenomena to which it gives rise. The prevailing opinion, however, among scientific men, is, that heat is a molecular motion, which may be generated by friction, percussion, compression, combustion, &c.

Some have conjectured it to be a kind of material fluid,

exceedingly subtle and etherial, diffused throughout all things, and capable of combining with every known species of matter. This supposed fluid has received the name of *Caloric.*

"This theory maintains that different substances have different capacities for holding heat, and that friction diminishes his capacity, bringing heat out of matter, as squeezing brings water out of a sponge.

But this is grossly erroneous, as proved by Davy. He rubbed two pieces of ice together, in a vacuum, and melted them by pure friction. The water produced contained a far greater amount of heat than the ice. Now the greater could not possibly be derived from the less.

Besides, the amount of heat that gaseous bodies naturally contain, is perfectly definite, while, on the contrary, the heat produced by friction is inexhaustible, and is utterly independent of the nature of the substance used.

This caloric hypothesis has been abandoned by the leading scientific men of the age.

"***The Essence of Heat is Motion.***—With a few exceptions, which are, perhaps, no exceptions, the universal effect of heat upon all matter is to expand it. We say that bodies are heated and cooled, and that one warms another near it; but we *strictly* mean only that they expand and contract, and that a body, in expanding, contracts others, and, in contracting, expands them. Hence, divested of everything not belonging to it, we find the effect of heat to be, simply, a *motion of expansion in matter*, communicable from body to body. Thus the essence of heat is *motion.* The motion of a mass implies the motion of its parts.

If a body expand, it is because its atoms have receded farther from each other, that is, have *moved.* Heat is, therefore, such a motion among the atoms of a body as gives rise to expansion. This idea was clearly enunciated, a hundred years ago, by the philosopher, *Locke*, who said, 'Heat is a very brisk agitation of the insensible parts of an object, which produces in us that sensation by which we denomi-

nate the object hot, so that what in our sensations is *heat*, in the object is nothing but *motion*.'

As heat is a motion of atoms; intensity of the motion determines temperature.

When a body is heated, the vibration of its atoms is augmented; the particles move through larger space; are urged apart, and thus cause the body to expand in bulk.

When the vibrations of the atoms of solids become sufficiently violent, they are loosened from the rigid grasp of cohesion, and, continuing to oscillate as before, they are now at liberty to slip or flow around and among each other.

This is the liquid state in which rigidity has disappeared, although a certain amount of lateral cohesion remains. A further augmentation of heat increases the swing of vibration until the atoms are thrown quite beyond the sphere of cohesion, and fly asunder into the vaporous or gaseous state. The ideas of the best-informed philosophers are, as yet, uncertain regarding the exact nature of the motion of heat; but the great point, at present, is to regard it as a motion of *some kind*, leaving its more precise character to be dealt with in future investigations.

A difficulty in acquiring the new view, is, that the current language concerning heat, implies the material hypothesis. It is so natural to regard heat as a *thing*—to ascribe a *substantive* existence to that which is the subject of a name, that it will be necessary to guard against the misleading tendency of the ordinary terms. The reader should strive to think of heat, not as an abstract thing, but simply as a contagious, or communicable motion of atoms."[1]

The Effects of Heat are:

1st. Expansion.—All solid bodies, except clay, are increased in volume or bulk by heat: thus, a sheet iron stove, in which a hot fire is quickly kindled, makes a cracking noise, in consequence of the rapid expansion of the metal.

[1] Youmans' Class Book of Chemistry.

Wheelwrights and coopers take advantage of this law. *Liquids*, when heated, expand much more than solids. Thus, water, raised from 32° to the temperature of 212°, increases in volume one twenty-second. The higher the temperature, the greater the rate at which liquids expand.

Aeriform bodies expand equally under a given increase of temperature. At 212° their volume is one-third greater than at 32°.

2d. Liquefaction.—The first effect produced upon solids by heat, is expansion. If the heat be increased, they melt, or become liquid, as is the case in the melting of ice, wax or lead.

The melting point of a given solid is always fixed and constant, but it varies greatly with different solids. Thus, mercury is melted at –39°; ice, at 32°; wax, at 142°; lead, at 612°; wrought iron, at about 2800°; and platinum, at 3280°. When a solid is converted into a liquid, heat is absorbed; when a liquid is converted into a solid, latent heat is given out. Ice cream, for example, is frozen with a mixture of salt and pounded ice; the latter is rapidly melted, and so much heat is absorbed in the process that the cream is frozen.

3d. Vaporization.—Heat, applied to a solid, first expands it, then melts, and finally converts it into vapor. Some solids, however, pass from the solid to the aeriform state, without becoming liquids. When a solid or a liquid is converted into a vapor, sensible heat is absorbed. In changing water into steam, nearly 1000 degrees of heat disappear. When the vapor is turned back to a liquid or solid, the latent heat is given out, or becomes sensible.

4th. Incandescence.—Heat, when imparted to bodies in a certain quantity, will, in many cases, render them luminous. If a piece of iron be heated to a certain degree, it becomes "*red hot*," which merely signifies that it emits a red light, and when "*white hot*," a white light. This luminous state is called incandescence. Coal, at 750°, is black; at 908° incipient red; at 1503° commencing red; at 1797° full

cherry red; at 2233° bright ignition; at 2951° dazzling white; and at 4347° intensely brilliant.

The Principal Sources of Heat are:

1st. The Sun,—which is the greatest natural source of heat, as well as of light, to the earth.

2d. Mechanical Action.—Every arrest of motion produces heat. Thus, a small bar of iron may be heated to redness by simply hammering it. Savages kindle fires by the friction of two boughs. Two pieces of ice may be melted by rubbing them together even where the temperature is below the freezing point. By drawing a match across a rough surface, we develop sufficient heat to ignite it. The friction of two large iron plates has been employed as a source of heat for warming factories. Compression and percussion are familiar methods of developing heat.

3d. Chemical Action.—The third source of heat is chemical, or the action of atoms of dissimilar substances upon each other, accompanied by complete change of properties. Examples of this are countless: thus, the mixing of quicklime with water. A single drop of sulphuric acid will set fire to a mixture of sugar and chlorate of potash. One of the most familiar processes in which chemical action is exhibited, is in the burning of fuel or illuminating substances. As the sun is the great source of natural heat and light, so combustion is the great source of artificial heat and light. To inquire into the changes which take place in the several substances employed during this process will be our object in the succeeding chapters. We have only, at present, to remark that combustion, in the ordinary acceptation of the term, is the rapid chemical union which takes place between the oxygen of the atmospheric air and certain elements contained in such organic substances as wood, peat, coal, and other varieties of fuel. The atmosphere, as the source of oxygen, claims a brief notice here. Fuel will be considered in the two following chapters.

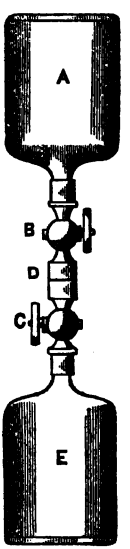
The Atmosphere.—The earth and sea are covered with a great but unknown thickness of elastic fluid, called the

atmosphere. Being gaseous, it consists of material particles, not held together by the force of cohesion, but nevertheless made up of atoms capable of forming solids. A hundred parts of pure air, in a dry state, contain twenty-three parts *by weight* of oxygen, and seventy-seven of nitrogen. One hundred *volumes* of dry air contains 79.12 *volumes* of nitrogen, 20.80 of oxygen, .04 of carbonic acid, .04 of carburetted hydrogen, with traces of ammonia. The physical and chemical properties of these several constituents will be considered in another place.

Let it be observed that the gases forming the atmosphere are not *chemically combined.* They are *mixed mechanically*, and each produces an independent effect, but there is no tendency in the several gases to separate. Taken from whatever part of the world, from the highest mountain, from the level of the sea, from the thickly wooded forest, or densely populated city, the proportion of oxygen and nitrogen is nearly the same.

If the jars A and E, Fig. 1, be filled with one-fifth oxygen and four-fifths nitrogen, and allowed to remain with the stop cocks B and C open, the gases will become so thoroughly mixed (even though we put all the oxygen in the lower jar) that each jar will contain just one half of both the oxygen and nitrogen. This mixture will give us an atmosphere capable of carrying on combustion or supporting respiration.

FIG. 1.



If the upper jar be filled with hydrogen, and the lower jar with carbonic acid, the light hydrogen will descend, and the carbonic acid, though twenty times heavier, rise, and they become equally mingled in both jars. Every gas seems to act as a vacuum for another.—Thus, as much steam can be forced into a space filled with dry air, as into a space containing no air or any other substance. As a consequence of this important law, the proportions of

atmospheric gases to each other are kept extremely uniform, being scarcely influenced by season, climate, wind or weather.

CHAPTER II.

Fuel,—General Considerations.

The word Fuel is derived from the French *Feu*, signifying fire, which is closely related to the Latin *Focus*, a hearth or fire place. The term embraces all those substances which are employed in the generation of heat, such as wood, coal, peat, oils, etc.

The abundance or scarcity of fuel is a subject of momentous importance to every nation, for it has an almost unbounded influence on the manners, customs and prosperity of the people. If ever the supply is cut off, manufacturing ceases, commerce declines, every branch of human industry is paralized, and man sinks back to the rude and degrading habits of savage life. In cold climates, where the supply of fuel is scanty, houses are small, the external air is excluded as much as possible, and the occupants are forced to live crowded together in a manner that is alike injurious to health and morals. The body becomes dwarfed, the intellect dull, and the standard of morality low. The diminutive and indolent Laplander whiles away in listless idleness the long and dreary winter, in a small hut, heated by the smoky lamp of putrid oil. What might not be accomplished, could these hours be devoted to the useful arts, and to mental and moral culture?

It has been remarked that the Frenchman is never at home except when he is abroad,—a witty paradox, which, nevertheless, conveys much truth. His language is even destitute of a name for the place we call *home*—a name dearer than any other to an American heart. Who can doubt that the scarcity, and consequent high price of fuel, has had a power-

ful influence in forming the customs and character of this nation, by transferring to the theatre and the coffee house, those attractions which, in our own and other countries, where fuel is abundant and cheap, belong to the domestic circle, the family fireside?

"The dismal and unceasing complaints about the wrongs of Ireland, have, of late, resounded loudly through the land. Englishmen and Scotchmen cheerfully accept the world as they find it, manfully struggle against obstacles, and die at peace with all mankind. Not so with the Irish. What is the reason? It may be tenant-rights, but there is another cause for the sad condition of Ireland, which does not seem to occur to the minds of most. This is the *want of coal.* There is Ireland, poor and complaining, a breakwater against the fury of the Atlantic waves, while England is rich and happy. These two islands are separated only by St. George's Channel; whence this difference of condition? Irish emigrants flock to the United States, and there prosper on account of the demand for white labor, and the consequent high rate of wages. They leave their native land ragged and penniless, while in America they live in comparative comfort, and in many instances accumulate property. Irishmen see England and Scotland prosperous beyond parallel, and they cannot understand why they themselves should not be equally so. They blame the British Government for this inequality of lot, and absurdly suppose they are the victims of gross injustice. No delusion can exceed that, on which is founded the claims for Government encouragement of Irish manufactories, as though, in these days of free trade, it were possible to establish and carry on manufactories in localities where the conditions are unfavorable. Ireland, for the most part, is a pastoral country, and no pastoral country can become as rich and prosperous in a material sense, as a country like Great Britain, with her vast stores of coal, or, in other words, of manufacturing power. It would seem that Irish wrongs are the results which cruel nature herself has committed at an extremely remote epoch,

for there is reason to believe that coal was once deposited over a large part of Ireland, and was wholly washed away, or, as geologists would say, removed by denudation."

An abundance of fuel is the basis of national wealth and prosperity, not only ministering to the useful arts, but enabling the occupants of every house to create an artificial climate suited to their own wants. It has been a prime necessity to man ever since he began to emerge from the depths of barbarism. His dependence upon it has been strikingly illustrated by the substitutes which he makes for it in passing over the barren wastes left by nature destitute of fuel. On the sandy plains of the East, camels' dung is dried and used for fuel. The Chinese have for a long time been accustomed to mix the excrement of the cow and other animals, and refuse vegetable matter with soft clay and the dust of coal, to form balls which, on being dried in the sun, become articles of commerce, and are transported by means of canals, to different parts of the empire.

The controlling agency of fuel in the development of body and mind, and in the preservation of health, has been so well shown by Tomlinson, in his excellent treatise on "*Warming and Ventilation*," that we subjoin the following extract:—"Some instructive results may be obtained from the inquiry, how far the physical structure and mental characteristics of men are influenced by the comparative scarcity and abundance of some of the prime necessaries of life. The unequal distribution of solar heat over the earth is the cause of marked difference in national character; and, where an artificial in-door climate is required, the ease or difficulty with which fuel is procurable, has a great effect in promoting or interfering with the health and personal comfort of nations, and thus, by a reflex action, contributes much to the formation of character. It has been remarked that formerly, the county of Buckingham being overgrown with wood, it was thought necessary to clear it away, on account of the refuge it afforded to the numerous robbers who infested the district. The people, being thus deprived

of fuel, became, in the course of time, stunted in growth and dulled in intellect; until, by the extension of inland navigation, fuel became cheap, and then the inhabitants began to improve. In the county of Lancaster, on the contrary, the great abundance and cheapness of fuel were extremely favorable to health and comfort, and hence, according to Sir Gilbert Blane, the Lancasterians, especially the females, have become noted for their well-formed persons and handsome faces. In Yorkshire, and other parts of England where fuel is abundant, the people are generally well-grown, healthy and intelligent, and their average height is said to exceed that in other parts of England, where fuel is scarce. The Norwegians are generally well lodged, each house being furnished with glass windows, and an iron *kakle*, or stove; and, on this account, they are a better grown race than the North-Western Highlanders of Scotland, who procure their fuel with difficulty, and consume it in a rude and unthrifty manner. In France, where fuel is scarce, the average height of a man does not exceed five feet four inches; in the Netherlands, where fuel is more abundant, the average height is five feet six and a half inches; and in England, where fuel is cheap and abundant, the average height is upwards of five feet nine inches; in Sweden, where wood is as abundant as our coal, the peasants are tall, vigorous men, notwithstanding their uncleanly habits and the rigor of the climate.

"I think it is Dr. Franklin who remarks, that where fuel is dear, working people live in miserable hovels, are ragged, and have nothing comfortable about them; but where fuel is cheap, they have decent habitations, and are well provided with the necessaries of life. The obvious reason is that the working hours of such people are the profitable ones, and they who cannot afford sufficient fuel, have fewer such hours in the day than those who have it cheap and plentiful; for much of the domestic work, whether of women or men, that requires but little bodily practice, cannot well be performed when the fingers are numbed with cold. Poor people, therefore, in cold weather, go to bed

earlier and lie longer in the morning, than they would if they had good fires to sit by; so that their hours of work are not sufficient to procure the means of comfortable subsistence.

The comparative scarcity or abundance of fuel will, of course, greatly determine the method of creating an artificial climate within doors. In some parts of China, where fuel is scarce, the people secure themselves from the cold of winter by warm clothing, and this is probably a safer method even than our own, because with them the defence is constant and uniform, while our indoor clothing is thin, and we rely for warmth upon an atmosphere heated to the temperature of summer.

In Normandy, where the cold of winter is severe, and fuel expensive, the lace-makers, in order to keep warm, and at the same time to save fuel, agree with some farmer who has cows in winter quarters, to rent the close sheds. The cows are tethered in a row on one side of the shed, and the lace-makers sit cross-legged on the ground on the other side, with their feet buried in straw. The cattle being out in the fields by day, the poor women work all night for the sake of the steaming warmth arising from the animals. An analagous practice is recorded of the Nottingham lace-makers, who are said at one time to have been in the habit of crowding together in a small room, for the sake of the heat engendered by their breaths, in spite of the poisonous atmosphere thus produced.

The Laplander, during eight months of the year, inhabits a little hut with a small hole in the centre of the roof, for the admission of light and the escape of smoke, and obtains heat from a smoky lamp of putrid oil, as the Esquimaux does in his hut of snow. The effect of this arrangement is, that the Laplanders are commonly afflicted with blear eyes. The Greenlander builds a larger hut, and contrives it better, but it is often occupied by half a dozen families, each having a lamp for warmth and for cooking, and the effect of this arrangement, according to the remark of a traveller, is

to create such a smell, that it strikes one not accustomed to it, to the very heart. It is to be feared that a similar effect would be produced on any of our readers, were they to enter the huts of some of the Irish and Scotch peasantry, or even the rooms of the poor in our large towns.

The method of obtaining warmth in Persia is scarcely an improvement on the smoky lamp of the Laplanders and Greenlanders. A large jar called a *kourcy*, is sunk in the earthen floor, generally in the middle of the room. This is filled with wood, dung, or other combustibles, and when it is sufficiently charred, the mouth of the vessel is shut in with a square wooden frame, shaped like a low table, and the whole is then covered with a thick wadded quilt, under which the whole family, ranged around, place their knees, to allow the hot vapor to insinuate itself into the folds of their clothing; or when they desire more warmth, they recline with the quilt drawn up to their chins. The immovable posture necessary for receiving the full benefit of the glowing embers is inconvenient; and the effluvia from the fuel is nauseous and deleterious. Head-ache is produced, and from the number who sleep entirely under the quilt at night, suffocation is not an uncommon accident. The kourcy also serves for an oven, and the pot is boiled on its embers. This rude and unwholesome method is adopted in the noblest mansions of the cities as well as in the dwellings of the poorer classes; only in the former, a more agreeable fuel is burnt, and the ladies sit from morning till night under rich draperies spread over the wooden cover, endeavoring to overcome the soporific influence of the foul air, by occasional cups of coffee, or the delightful fumes of the *kalioum*.

The burning of fuel in the midst of an apartment is by no means confined to nations which we are in the habit of calling barbarous and uncivilized. In Seville and other parts of Spain, preparations for winter are made about the middle of October. The lower summer apartments are stripped of their furniture, and the chairs and tables are removed to other rooms on the opposite side of the court. The brick

floors are covered with thicker mats than those used in the warm season. A flat and open brass pan about two feet in diameter, raised a few inches from the ground by a round wooden frame, on which those who sit near it may rest their feet, is used to burn a sort of charcoal, made of brushwood, called *cisco*. The carbonic acid given off by this fuel, is injurious to health; but such is the effect of habit, that the natives do not refer their ailments to the stifling fumes of their braziers."

The interest which this subject is exciting in Great Britain is clearly shown by the following extract from an article found in a recent number of the London Quarterly Review: "There is no question of more momentous concern to Great Britain than that of the duration of her coal-fields. It is a question which of late has excited the attention both of statesmen and philosophers. It was referred to in anxious terms by Mr. Graham, the member from Glasgow, at the recent opening of Parliament.

Sir Robert Peel, in his speech of the 9th of March last, in the House of Commons, on the nuisance arising from the smoke of furnaces in towns and rural districts, sounded notes of alarm at the enormous and yearly increasing consumption of coal, and, in the course of debate which followed, other speakers expressed similar apprehensions. It will not be denied that our marvelous prosperity has mainly resulted from our manufacturing power, and that this power is, for the most part, to be ascribed to our coal. It is also evident that the position of Great Britain among the nations of the earth depends on her wealth, and that this wealth has been chiefly accumulated by manufacturing enterprise. Hence the '*Coal Question*,' as Mr. Jevons terms it, may be justly considered as of vital importance to all the dwellers in the land, high as well as low, rich as well as poor.

Waste of Coal.—This question may be considered under two heads; the first is, waste in procuring; the second is, waste in burning. Waste in procuring is partly inevitable, and partly preventable. Every blow of the pick reduces

some of the coal to comparative powder, and the amount of waste from this cause will vary with the quality of the coal as to tenderness, and with the character of the bed, especially as to joints. There are several systems of getting coal which, for want of space, we are unable to describe. A comparison of these with each other would clearly show that while loss takes place with all, they differ considerably as to the degree of waste. Of all the coal seams of Great Britain, the greatest waste has occurred in that known as the ten yard, or thick coal of South Staffordshire. The seam ranges in thickness from eight to ten yards, and is composed of several distinct beds, varying much in quality. It is now nearly exhausted. With very few exceptions, it has been worked on the "pillar and stall" system. Huge pillars, about ten or twelve yards square, with enormous ribs, have been left from the first working. The residual coal was imperfectly extracted in a second working, and some of the old pits have been rifled even several times in succession. This coal is wholly non-caking, and it may be confidently asserted that millions of tons of its slack now lie buried in the worked out collieries of South Staffordshire, it is to be feared, without hope of resurrection. Yet every ton of that slack has, stored away in it, as much heat-giving force as the same weight of solid coal.

It is a fact known to every well-informed colliery engineer in the kingdom, that the working of this fine coal-seam, far exceeding in thickness any other in Great Britain, has, for the most part, been entrusted to unskillful or unscrupulous persons. Indeed, at one time, even the bare mention of the term, colliery engineer, in South Staffordshire, was regarded as a joke, and excited sceptical laughter. But it was no joke, either to proprietors, lessees, or the nation. It is scarcely possible to over-estimate the destruction of coal which formerly resulted from a combination of ignorance and roguery.

With regard to the total waste of coal in all the collieries of Great Britain by the destructive practice already

described, or, by burning at the pit's mouth, great heaps of small coal dust, it is not possible to present any precise or trustworthy information. There is too much reason for apprehension that it greatly exceeds what the public may suppose, or what the workers of collieries would be willing to admit. One illustration, on undeniable authority, will suffice. The late Mr. Nicholas Wood asserted in 1861, that the waste at the Helton and Black Bay Collieries alone, amounted to 160,000 tons of small coal in a year! From information collected at the Museum of Practical Geology, it would seem that, last year, about 96,000,000 tons of coal were raised; it would probably be safe to add to this number, at least 20,000,000. In other words, in round numbers, we are raising 120,000,000 tons of coal yearly. In 1860, the quantity raised was 80,000,000 tons; in 1856, about 66,600,000 tons. These numbers are so large that it is difficult to form any accurate conception of their actual value. With 100,000,000 tons, a girdle of coal three feet wide, and about seven feet high, could be put round the earth!

The next point for consideration, is the waste of coal in burning. In common domestic fires it has been computed that seven-eighths, and even more, of the heat capable of being evolved from the coal, passes up the chimney unapplied, so far as mere warming is concerned; and, whether this estimate be exaggerated or not, it is undoubtedly true that the proportion of heat lost, and consequently of coal wasted, is very large. About half of the heat generated by fire is supposed to be carried off with the products of combustion, and the remaining loss of heat is represented by the unconsumed combustible gases, and unburned particles of carbonaceous matter, in the form of smoke. It is this which renders coal smoke so dark and offensive, and which is partly deposited as soot. We need no further proof of the quantity of fuel wasted in this manner, than what is afforded by the observation of a chimney on fire. But an English fire-place is so cheerful and attractive, even though we may be roasted on one side and frozen on the other, what

matters the waste of fuel? Moreover, it is argued that the open fire-place causes excellent ventilation. Doubtless it does, but not so effectually as to remove the air which has become most vitiated, that at the upper part of the room. Our lower limbs may thus be refrigerated, while our heads are immersed in the contaminated air above. The open fire warms by radiation, and long habit has wedded us to the system, in spite of its manifold defects, not the least of which is, waste of coal,—a mineral which it needed no Sir Robert Peel to inform the House of Commons, is more precious to us than all the silver of Mexico and Peru. In the *good old times* in England, our ancestors seem to have been as lavish in their consumption of wood, of which, in those days, there was no lack, as we are at the present time with respect to coal. If we could only be induced to give up our prejudices, and prefer reality to semblance, there would be no difficulty in warming and ventilating our houses, with a fraction of the coal now used.

Deleterious effects of Smoke.—But economy is not the only incentive to the saving of coal in our households. It is really distressing to notice the vast difference between the quality of the atmosphere of London and other large towns, and that of the country or many cities of the continent,—Paris, for example. Here we are, in the metropolis, breathing coal smoke, begrimed by coal smoke, and sometimes involved in that pitchy cloud of infernal darkness, through which we see the sun dimly as a fiery-red ball. Our buildings are made hideous by coal-smoke, being patched with horrid streaks of black, where the rain fails to penetrate. The things we call statues, though made of bronze, are blackened with soot. If we keep our rooms closed, the ubiquitous smut gains access, and if we open them—as we must—wo betide us! Not only do our hands and faces contract dust, but soot finds its way into the air-tubes of our lungs. Plants, as well as animals, are poisoned by smoke, and struggle, often vainly, for existence in the parks of London. The fine trees in Kensington Gardens are dying apace, and roses

bloom not within some miles of Charing-Cross. Then, how great apprehension falls on our spirits from the fuliginous exclusion of the pure light of the sun. Tyndal tells us that the aqueous vapor in our atmosphere keeps us warm like a blanket, and so prevents us from being speedily frozen to death, but what is that dense canopy of coal-smoke over our heads, but a veil, which makes man wretched and nature hideous? This is not the language of exaggeration, and what seems so bad in description is far worse, if possible, in reality, in many manufacturing towns of the country. With us the evil is now caused by the imperfect combustion of a very large quantity of coal in our domestic fires. In the country the factories are vomiting forth huge volumes of smoke. Lancashire contains some of the filthiest towns in the kingdom, and smoke has done and is doing most of the mischief. Why do not the rich possessors of these mills, who generally take care to reside as far as possible from them, show some regard for the health and comfort of their working people? They declaim loudly enough in Parliament and elsewhere, against the employment of agricultural labor, and prattle on the rights and virtues of working men, but can they say that they themselves have done their duty to the laboring classes, while they knowingly inflict such an intolerable nuisance upon a large and, for the most part, dependent population?

Can a Substitute for Coal be found?—We know men highly educated after the usual fashion, in everything except physical science, and men, too, in a powerful position either to instruct or mislead the public mind, who fancy that a substitute for coal will be found. In the first place, they forget that for our purpose it would not be sufficient that a mere substitute should be discovered. To enable Great Britain to maintain her place among the nations, she should have as peculiar advantages in respect to the supposed new fuel, as she now possesses in respect to coal. But to return to our speculations. They point to wonderful inventions which in our time have proceeded from the brains

of men, and they argue that as our ancestors had not the faintest notion of the possibility of such achievements, so there may still be occult powers in nature, hereafter to be revealed, of which we have no conception. Hence they rashly jump to the conclusion that the power now supplied by coal, will, in the future, be derived from another source. Now if we examine the achievements above referred to, for example, steam navigation, railway travelling, and the electric telegraph, we shall find that they consist, not in the discovery of any new force, but simply in the new application of forces already known. Suffice to add that every day strengthens the conviction of those who are spending their lives in the pursuit of science, or, what is equivalent, in searching out the forces of nature, that the idea of a substitute for coal or similar carbonaceous matter, is the baseless fabric of a vision. Let us reflect for a moment on that prodigious amount of pent force, which may be set free by the application of a tiny spark, and then try to conceive of the possibility of any source of power, so abundant, so condensed, so available and so easily transported to any place that may be required. Mr. Jevons states the truth clearly in the following passage:—

"Coal has all the characteristics which entitle it to be considered the best natural source of motive power. It is like a spring wound up during geological ages for us to let down. Coal contains light and heat bottled up in the earth, as Stevenson said, for tens of thousands of years, and now again brought forth and made to work for human purposes. The amount of power contained in coal is almost incredible. In burning a single pound of coal, there is force developed equivalent to that of 11,422,000 pounds falling one foot, and the actual available power obtained from each pound of coal, in a good steam engine, is that of 1,000,000 pounds falling through one foot, that is to say, there is *spring* enough in coal to raise a million times its own weight a foot high. In coal we pre-eminently find, as the partner of Watt said, 'what all the world wants,—POWER.'"

All things considered, it is not reasonable to suppose or expect that the power of coal will be superseded by anything better. It is naturally the best source of power, as air, water, gold and iron, are, each for its special purpose, the most useful of substances, and such as will never be superseded. The question of the duration of our coal-fields is, as we have stated, being gravely discussed at the present time, by persons who have studied the geology of Great Britain, and have watched the enormous drain upon our collieries of late years. Of course, complete and absolute exhaustion of our coal-beds must come; it is only a question of time. Such an obvious proposition as this would seem superfluous, but it is not so, for, only a few years since, it is reported that the first statesman of the day believed in the growth or reproduction of coal! Coal once gone, is gone forever, so far as we are concerned. The carbonic acid gas which it produces on combustion, may serve as food for plants in this and other parts of the world, and thus its carbon, by the aid of sun force, may again be deposited in a form available for fuel. But it is certain that no flora now exists in any part of the world, either in kind or luxuriance of growth, like that which formed the coal of the carboniferous system. Sir William Armstrong, in his address, which, as President, he delivered before the British Association, at Newcastle-on-Tyne, in 1863, uttered a mournful yet salutary warning as to the end of our coal, and we believe that he spoke the truth, and that the end is much nearer than is commonly supposed. Nations, like individuals, are liable to be reckless as well as lavish, and go on scattering their resources broadcast, until they suddenly find themselves ruined beyond all redemption. Thus have we sinned with regard to our coal, that matchless reservoir of force, and thus shall we fall from our high estate, if we proceed in our mad career of extravagance and waste. Prophets have arisen, proclaiming our apprehensions to be unfounded, and the end far distant, but they present no credentials worthy of our acceptance. We flatter ourselves that coal will last our time,

and so it will; but men who are susceptible of patriotism, look forward with anxiety to the future of their country, and unless measures are adopted to prevent the continuance of the enormous waste of one of nature's richest gifts, succeeding generations will have bitter cause to deplore our folly in this respect, and to regard us as spendthrifts who have ignorantly or knowingly destroyed so much of that power, by the application of which we have, in a great measure, achieved our prosperity and high position among the nations of the earth."

Fuel in the United States.—It is hardly necessary to reiterate the well-understood and indisputable, fact that an abundant supply of wood and coal, easily procured, has contributed more than any other resource, to the rapid growth and national prosperity of the United States. In no country has nature been more lavish in the distribution of her bounties, and nowhere have her choicest gifts been more wantonly and recklessly squandered. In many towns in the Eastern States, where, fifty years ago, wood was considered a nuisance which every proprietor of land was trying to get rid of, it is now valued at six or eight dollars a cord. The demand is still rapidly increasing. On account of the high price of labor and cost of transportation, supplies of fuel from our rich and inexhaustible coal fields, can be available to many localities only at exorbitant prices, hence our forests are as yet the chief source of supply to a very large portion of our country. The rapid destruction of these cannot have escaped the attention of the most casual observer; while the entire lack of care for their preservation, or effort for their restoration, must awaken in every thoughtful mind an anxious solicitude for the future. The work of destruction still goes on, increasing in vigor and extent. While we write, the murderous axe of the New England farmer is ringing from a hundred hill-sides, and echoing from as many valleys, telling too plainly of the sad havoc committed among our majestic pines, stately oaks and noble maples. And unless some energetic measures are adopted for their preservation,

ere long modern civilization will have swept away the pride and beauty of those noble forests, which waved so majestically over our land when the Mayflower touched upon New England shores.

The high price which coal and wood have commanded for several years, has compelled all classes to fully appreciate the importance of this subject. Our public journals are agitating the question, and a paper has recently been started in Boston, devoted exclusively to the subject of fuel. Inventive genius and mechanical skill are hard at work in endeavoring to devise some means by which the "*black mud*" of our swamps and bogs may be made serviceable as a substitute for wood and coal. The results of numerous experiments inspire the enterprising managers of this new branch of industry with confidence and hope, but as yet the supply of fuel from this source has hardly been sufficient to keep pace with the increasing demand. The draft upon our forests still continues, and seems likely to continue, unless some effective measures are adopted to stay their devastation, until they have disappeared from our sight forever. To enter into an investigation of the many unhappy and disastrous results which will inevitably flow from this wholesale destruction of our forests, would require a volume much larger than this, yet we cannot refrain from enumerating enough of these to demonstrate to the reader that our forest trees possess a value far beyond our ordinary estimation or conception.

Were we not emphatically a utilitarian people, the magnificent beauty of our forests would alone be a sufficient argument for their preservation. How much more pleasant to the eye is a hill-side with its graceful trees, draped in foliage of the richest verdure, than a barren summit, destitute of nature's own protection? Who would exchange the tree-clad hills of New Hampshire or the evergreen moutains of Vermont, for the sterile wastes of Nantucket, or the monotonous flats of New Jersey? The unrivalled autumnal beauty of our forests is ever gazed upon by the old and the

young with unwearied delight, and calls forth expressions of enthusiastic admiration from the European traveller. The brilliant orange hues of the sugar maple, the gold and green of the elm, the modest yellows and unassuming buffs of the birch, the bright yellows and deep scarlets of the oak, the rich browns of the bass wood, and darker hues of the ash, the unfading green of the firs, pines and other evergreens,—all these, intermingled and blended with richest tints of purple, crimson and gold, in numberless forms and shades, ever changing to the eye of the traveller, like nature's grand kaleidoscope, present a sight which, in gorgeous beauty outrivals our highest conceptions of imperial magnificence.

Utility of Forests.—But the delightful charms which forests afford to the appreciative student of nature are by no means the chief reason why they should be protected from the unsparing axe of the mercenary lumberman. The God of nature did not create these, with their matchless variety of form and color, simply as a mantle of beauty, to conceal bald rocks and cover naked hills, or to decorate, with fringes of emerald bloom, crystal lake and sparkling stream, but for indispensable practical uses. These are so multifold that we can mention only a few of the more direct and prominent.

Forests check the movement of winds and thus in a sensible degree modify the temperature of climate. In Italy the clearing of the Appenines is believed to have greatly affected the climate of the Valley of the Po, for the sirocco now prevails on the right bank of that stream in the region of Parma and in parts of Lombardy, where formerly it was unknown. It is stated that when the extensive pine forests in the neighborhood of Ravenna were cut down, the inhabitants began to suffer; afterwards the woods were allowed to grow, and the city is now free from the enervating influence of the sirocco, and its old climate restored. When English iron was excluded from Italy by the influence of Napoleon I., the furnaces of the valleys of Bergamo were worked to their utmost capacity. As the ordinary supply of charcoal was

not sufficient to feed them, the young as well as mature trees were felled, and the whole economy of the forests was deranged. At Piazza Torre, there was such a wholesale destruction of the wood, and consequently such an increased severity of climate, that maize no longer ripened. After a prodigious effort, the forests were restored, and grain again flourished in the fields of Piazza Torre. In France, since the destruction of the forests of the Cevennes, which protected a large and rich tract of land, near the mouth of the Rhone, from Northwest winds, the olive has retreated many leagues, while the orange is confined to a few sheltered points along the coast. In Belgium, trees have been planted on the right bank of the Scheldt, where before there was no vegetation; the shelter thus afforded by these young forests has rendered fertile large tracts of land which were formerly barren wastes.

Forests exercise a powerful influence on the quantity of rain and dew. The aridity of Spain, occasioned by the absence of wood, not unfrequently renders the crops too wretched to pay for gathering. Many districts in France have suffered from the same cause, and trees are now being planted with a view to restoration. In parts of Scotland, many miles square have been planted with trees, attended with happy results. During the French occupation of Egypt, in 1798, at Cairo and Alexandria, rain did not fall for sixteen months. Since, however, Mehemet Ali and Ibrahim Pacha completed their vast plantations, (the former alone having planted more than twenty millions of olive and fig trees, cotton-wood, oranges, &c.) there falls a frequent and liberal supply of rain.[1]

Forests act as copious reservoirs for retaining the water after rain has fallen. The foliage of trees retains a large quantity of water, thus preventing a rapid and destructive rise of streams. Water is also held by the accumulation of dead leaves, which tends to check the formation of dangerous

[1] Geo. P. Marsh on Man and Nature.

torrents, and prevents sudden failures of streams in mountainous districts. Forests, by shielding the earth from the rays of the sun, greatly retard evaporation from the soil, consequently we are saved from severe drouths in summer. In many localities in New England crops have seriously suffered from this cause since the removal of the forests. We have in mind several small streams which were reliable for motive power for nine months in a year, but since the removal of the wood from the surrounding country, they can be depended upon for scarcely three months. Mr. Marsh tells us that many cases are recorded upon the best authority, of streams flowing from woods diminishing both in number and volume as the woods were removed. He also speaks of a case where a small mountain spring disappeared soon after the clearing of the ground where it rose, and was recovered about twelve years afterwards by simply allowing the bushes and young trees to grow upon a rocky knoll immediately above it. Boussingault, in his "Etudes sur les Inondations," mentions some very curious and interesting facts, illustrating the point in question. He tells us that the Valley of Aragua, in Venezuela, (South America), is shut in, and several rivers entering into it form a lake of considerable size at an elevation of 1460 feet above the sea. At the time Humboldt visited this valley, in the year 1800, there was a population as dense as in any of the best peopled parts of France, who had cleared the surrounding country of wood, and for thirty years the lake had been gradually lowering. Thus, in 1555, the town of New Valencia was formed on its banks half a league from the lake, and in 1800 the distance had become about three miles and a third, the water having receded nearly two miles. The intervening land was covered with plantations, and many hillocks retained the names of the islands of which they had previously formed a part. In 1822, Boussingault visited the valley, and found that the waters were gaining on the land. Islands, once cultivated, had become mere shoals. Fertile fields had become submerged, and the inhabitants were fear-

ing that they should be drowned. The cause of this was that certain political events, which had intervened, had produced an interruption of labor, and the forests had regained their strength.

Forests purify the Atmosphere. The vegetable kingdom is the grand laboratory in which the poisonous products of combustion and respiration are decomposed and rendered harmless. The leaves of plants contain millions of minute pores or mouths, through which they inhale carbonic acid, decompose it, retain the carbon as material for growth, and return the oxygen to the atmosphere. They also absorb water, decompose it, retain its hydrogen, and give back the oxygen to the atmosphere. Plants sometimes take nitrogen directly from the atmosphere, and also sometimes indirectly from nitric acid. Thus it appears that the chemical function of the vegetable kingdom is directly the reverse of that of the animal kingdom. The animal kingdom is an immense apparatus for combustion, which poisons the atmosphere. The vegetable kingdom is an equally grand apparatus for reduction, which purifies the atmosphere. A forest withdraws, by the enormous absorbent surface of its leaves, much more carbonic acid than meadows and cultivated fields, and gives out much more pure oxygen; hence, the removal of forests cannot fail to affect the atmosphere.

In brief, we may say, that forests equalize the temperature of our climate, by shielding us from the violence of chilling winds, and the parching rays of an American sun; increase the yearly supply of rain; prevent irregularity in our streams; enrich our soil, by their constant annual deposit of leaves; purify the atmosphere; bind the earth to the hill-sides, thus preventing it from being washed away by heavy rains; to say nothing of the abundant supply of material afforded for our dwellings, warehouses, machinery, implements of husbandry, etc., or of valuable barks, roots and nuts for coloring, dyeing, medicinal and other purposes, or of rich supplies of syrup and sugar from the maple, or of pot and pearl ash for the fertilization of our exhausted soil.

On the other hand, their removal must inevitably occasion a rapid loss of heat, by radiation, during one season of the year, and an undue supply, by direct exposure, during another, thus chilling the soil in winter, and parching it in summer; the annual fall of rain is diminished; the elements of a productive soil become exhausted; the surface of uplands is washed away by torrents, while the valleys are covered with sand and rocky fragments; the channels of the larger streams are choked, and navigation obstructed by the formation of sand bars.

In view of these important facts, shall we learn no lessons of economy, prudence and wisdom? England and other nations have sinned in this particular, and are now reaping the bitter fruits of their reckless extravagance. Shall we suffer this incalculable wealth of vegetable life to be ruthlessly squandered by a mad cupidity, which in the end will surely overreach itself. On the continent of Europe the management of natural forest trees receives the greatest attention, and is systematically and scientifically conducted, and the formation of forests by sowing seed is now generally practiced. May not our forests be thinned and husbanded, instead of being utterly destroyed? May not the cold soil of our northern States be rendered doubly productive under their grateful shelter and protection, and the flow of our streams be kept constant for manufacturing purposes? And may not the preservation of our forests be, in some degree, instrumental in securing to our population that vigor, both of body and mind, which characterizd our ancestors of a few generations ago?

CHAPTER III.

Physical and Chemical Properties of the Different Substances used for Fuel.

Wood.—This is the most common and widely distributed of all the substances used for fuel. Recently felled, it consists chiefly of woody fibre, sap and water. Woody fibre, which forms the principal bulk of plants, is composed of carbon, oxygen and hydrogen. The sap constitutes only a small proportion of the bulk of wood, and varies much in different kinds of trees. The sap of the pine and other cone-bearing trees contains resin; that of oak, tannin; that of maple, sugar. The amount of water in wood varies greatly with the kind of tree, and the season of the year when it is cut. Trees contain more water at the time when there is an active flow of sap, and soft woods contain more than hard. On exposure to the air, after being cut, a portion of the water evaporates, one hundred pounds weight having been known to lose twenty pounds in ten or twelve months, yet a large proportion remains, for air-dried wood, as commonly used, contains about thirty per cent. of water. Twelve or fifteen per cent. more of the water may be expelled by exposure to artificial heat in a kiln; but before all the moisture is evaporated, the wood begins to char, that is, the volatile portions are separated from the fixed carbon. As water is not combustible, its presence in wood diminishes its value as fuel. The water must be driven off at the expense of the heat generated by those

portions of wood which are combustible. The water can be expelled only by converting it into steam, and this process requires a large expenditure of heat. If one hundred pounds of wood contain thirty pounds of water, there would remain but seventy pounds of combustible matter. It will require one pound of wood to raise the thirty pounds of water to the boiling point, and six pounds more of wood to convert it into steam, making an expenditure of seven pounds, or one-tenth the combustive material of the wood. Besides this waste of ten per cent. by evaporation, the presence of water prevents that free and rapid combustion which is essential for obtaining the maximum amount of heat from a given quantity of fuel.

Value of Different Kinds of Wood for Heating Purposes.—Some varieties of wood are soft and light; others, having their fibres more densely packed, are hard and heavy. Soft woods kindle easily, and are more active in combustion during its first stages, while harder varieties are more active during the latter stages. The soft woods burn with a large volume of flame, while hardwood gives little flame, and produces a large amount of coals. The cause of this is that the soft woods contain an excess of hydrogen, which (as will be shown hereafter) takes up an immense number of the atoms of carbon, producing flame, and not unfrequently smoke. The common opinion that soft wood, taken pound for pound, evolves less heat than hardwood, is erroneous. It is sooner consumed, because it is more porous and admits the air more freely, but it gives out an intense heat while it lasts, and is therefore well adapted to those purposes where a rapid and powerful heating effect is required, as for the generation of steam.

Some very important experiments on the relative heating qualities of the different kinds of American woods have been conducted with great care and exactness by Marcus Bull. The following table shows the relative heating values of several of the more common varieties of wood, according to the results which he obtained. Shell bark hickory is

taken as a standard, and the comparison, in all instances, is made with equal bulks.

Shell-bark Hickory, (*Carya Alba*)	100
White Oak, (*Quercus Alba*)	81
Red Oak, (*Quercus Rubra*)	69
Hard Maple, (*Acer Saccharinum*)	60
White Ash, (*Fraxinus Americanus*)	77
Soft Maple, (*Acer Rubin*)	54
Chestnut, (*Castanea Vesca*)	52
White Beech, (*Fagus Silvestris*)	65
Black Birch, (*Betula Lenta*)	63
White Birch, (*Betula Populifolia*)	48
Pitch Pine, (*Pinus Rigida*)	43
White Pine, (*Pinus Strobus*)	42

Charcoal.—This variety of fuel is a black, brittle, inodorous, tasteless solid. It is produced by depriving vegetable substances of their volatile constituents. This is effected by the agency of heat. The wood is piled so as to form a mound, and is then covered with turf and soil, in such a manner as almost entirely to exclude the admission of air, and thus prevent complete combustion. A sufficient volume of air is admitted to keep up a slow combustion for several days, or, if the quantity is large, for several weeks. When the wood is thoroughly charred, the air is entirely excluded, and the combustion ceases. The charcoal produced retains the form of the wood, but is much reduced in size and weight, seldom amounting to more than three-fourths the bulk of the wood, and one-fourth the weight. A cubic foot of charcoal from soft wood weighs eight or nine pounds; from hard wood, twelve or thirteen pounds.

Charcoal, newly made, burns without flame, but it soon absorbs moisture from the atmosphere, which is condensed in its pores. When this charcoal is burned, a portion of the water is decomposed, and hydrogen is set free, which takes fire and burns in connection with the carbon, producing a small volume of flame. Charcoal ignites readily, and gives a large amount of heat, but the fire needs frequent replenishing, as it consumes rapidly. At high temperature

Charcoal has a very powerful affinity for oxygen, and is of great service in reducing metals from their oxides in the smelting furnace. Charcoal has one advantage over wood, bituminous coal, and every kind of fuel containing hydrogen, namely, that the products of combustion are dry, whereas if hydrogen is present in fuel, water is always formed in considerable quantities, every ounce of hydrogen producing nine ounces of water.

Mineral Coal.—This variety of fuel consists of carbon together with some bituminous substances composed of carbon and hydrogen. There is always present more or less of earthy impurities, as silica, alumina, oxide of iron, sulphur, etc. Coal gives unmistakeable evidence of having been derived from an ancient vegetation long buried in the earth, and subjected to a slow and incomplete combustion. All vegetable tissues consist chiefly of carbon, hydrogen and oxygen. Dry vegetable matter contains about forty-nine per cent. of carbon, six and three-tenths of hydrogen, forty-four and six-tenths of oxygen. If we abstract from the wood the greater part of its oxygen, and submit the remaining constituents to a pressure sufficient to render them very compact, the product formed will resemble in every respect, the softer and more inflammable varieties of coal. When large quantities of vegetable matter are buried in the earth, with an almost entire exclusion of the air, a similar result is obtained. Most of the oxygen, and a small portion of the hydrogen of vegetable tissues, escapes, and a residue rich in carbon and hydrogen is left. These hydrocarbons, asthey are called, variously affected by heat and pressure, furnish all the different varieties of coal.

Properties of Coal.—The purest coal yields on combustion only one and a half per cent. of ash. That which is less pure contains ten, twenty, or even fifty per cent of uncombustible matter. At this last point the per centage of carbon and hydrogen is too small for ready combustion. The character of the coal is lost, and it is known as *shale* or *slate*.

The impurities of coal are derived in part from the wood. *Silica* is contained in many species of plants; this would remain in the coal. Potash is present in all vegetation; this might disappear, as its compounds are soluble. *Sulphur* and *iron*, in minute quantities, are also contained in vegetable matter; during decomposition, the sulphur would combine with the iron, forming pyrites, (sulphuret of iron) a very common and pernicious impurity in coal. When the sulphuret of iron is present in any considerable quantity, it renders the coal worthless for very many important purposes. On the application of heat, the sulphur combines with oxygen, forming sulphurous acid, a noxious gas, which corrodes, and seriously injures the quality of iron. The quantity of saline and earthy substances found in the tissues of plants, seldom exceeds fifteen per cent. Hence, when the percentage of incombustible matter in coal rises above this, it must have been introduced as earth or clay, by the action of wind, water, or other forces.

Prejudice against the use of Coal as Fuel for Household Purposes.—So long as wood existed in abundance, coal was not sought for, for purposes of domestic fuel. It was supposed that the fumes of coal had a peculiarly contaminating effect upon the air, and were most injurious to health. Its value, however, was appreciated by brewers, dyers, smiths, and others whose occupation led to the consumption of large quantities of fuel, and toward the close of the thirteenth century coal was imported into London from Newcastle, for the uses of these trades. In 1306 a royal proclamation was issued prohibiting the use of coal, and as this failed of its effect, a commission was issued for the purpose of ascertaining who burned sea coal in the city and its neighborhood, and to punish such by a fine for the first offence, and by the demolition of their furnaces if they persisted; but even these severe proceedings proved ineffectual. A law was therefore passed, making the burning of sea coal within the city, a capital offence. In the reign of the first Edward, a man was actually tried, condemned and executed

under this statute. So deeply rooted was the prejudice against coal, that it was not until the commencement of the seventeenth century that its use became general. Ladies had an idea that it injured their complexion, and they would not even enter a house where the obnoxious fuel was used, nor would they partake of meat which had been roasted at a coal fire."[1]

Varieties of Mineral Coal.—The two principal varieties of mineral coal are *Anthracite* and *Bituminous*. The former is the most condensed, and the richest in carbon of any variety known. Some specimens contain seventy per cent of carbon. It is stony, very compact, and possesses a high lustre, in color varying from jet black to a dark lead grey. Its density and freedom from volatile matter, make it an excellent conductor of heat, and thus prevent its ready ignition. Hence, to kindle it, we are obliged to use some substance like wood or charcoal, which will easily take fire, and evolve sufficient heat to raise a large mass of the coal to the point of ignition. When once thoroughly fired, it burns for a long time, emitting an intense concentrated heat. It gives but little flame, consequently its illuminating power is very feeble. Anthracite coals are often divided into the classes *red-ash* and *white-ash*, according to the color of the earthy impurities which remain after the coal has been consumed. The red-ash coal owes its color to oxide of iron, which it contains in considerable quantity. It is generally more easily ignited, and is a freer burning coal than the white-ash, but is not so much used in furnaces where considerable draft is required, owing to its liability to clinker, or form cinders, which melt and adhere to the lining of the fire chamber. Anthracite has been employed in this country since 1820, for heating purposes, and, during the last twenty years, for culinary purposes, both in close stoves and open grates. The advantages it possesses are, long continuance of uniform heat during combustion, the little attention required, its freedom from smoke, and its small liability to

[1] Warming and Ventilation, by Tomlinson.

communicate fire from sparks. It has high evaporative powers, but from the intensity of its combustion, it causes the iron bars of the grate, and the boiler, to oxidize rapidly.

Bituminous Coal.—This is a mechanical mixture of carbon and bitumen. Bitumen is a general name for certain compounds of hydrogen and carbon, which result from the decomposition of vegetable substances. It resembles pitch or tar, and is highly inflammable. Bituminous coal varies indefinitely in the amount of bitumen it contains, and some of its varieties gradually pass into anthracite.

Pitching or Caking Coal is a variety of bituminous, which breaks into small pieces on the first application of heat, but at higher temperature unites again into a solid mass. It burns readily in an open grate, with a bright yellow flame, but requires frequent stirring to prevent its caking so as to obstruct the admission of air.

Cherry Coal resembles caking coal in appearance, but does not, when heated, clog the fire, by softening and running together. It burns with a lively yellow flame.

Cannel Coal is a dry and highly bituminous coal of close texture, and possessing a faint lustre. It is obtained in rectangular blocks with smooth clear surfaces, which break with a large conchordal fracture. It is remarkable for the readiness with which it ignites, being kindled at once in the flame of a lamp, and continuing to burn with a highly luminous yellow flame, without melting. This property renders it well adapted for illuminating purposes and has given to it the name of *cannel*, which is the pronunciation of the word *candle* in Lancashire, where the name was first applied. In Scotland, farmers use it as a substitute for candles. It is also extensively used for the manufacture of illuminating gas. It is susceptible of receiving a fine polish, and is often made into boxes and other articles. *Cannel* coal is found in Virginia, Ohio, Kentucky, and Missouri, often forming layers in beds of common bituminous coal. It differs from other varieties in yielding a larger amount of volatile matter, some specimens containing less than eight per cent.

of fixed carbon. The quantity of ash produced is also large.

Asphaltic Coal.—This is a jet black and highly lustrous variety, closely resembling mineral pitch or asphaltum. It is found at the Albert mine in New Brunswick.

Lignite is a name given to a less perfect variety of coal, of a black or brownish-black color. It often shows the structure of the original wood. Its heating value is small, and in burning, it emits an empyreumatic odor.

The following are the most essential properties of a good coal for producing steam, and for domestic uses:

1. Great actual heating power.
2. Readiness to ignite, and rapidity in burning.
3. Small quantity of earthy matter, and this as infusible as possible.
4. Absence of Sulphur.
5. Freedom from clinkerage.

Relative Heating Value of Different Varieties of Coal.

The qualities of American Coals have been fully investigated by Prof. W. R. Johnson, and the results are presented in a condensed form in the following table:

VARIETIES OF COAL.	NAMES OF SAMPLES.	Relative evaporative power of equal *weight* of coal.	Relative evaporative power of equal *bulk* of coal.	Relative freedom from tendency to clinkerage.	Relative rapidity of action in evaporating water.	Facility of Ignition.	Sum of relative values in the preceding columns.
Cumberland, Md. Free-burning Bituminous.	Atkinson and Templeman's	1000	1000	282	828	505	3615
	Easby's and 'Coal in Stove'	936	946	451	658	286	3277
	Easby and Smith's	931	903	197	886	329	3246
	N. Y. and Md. Mining	914	927	111	677	376	3005
	Neff's	882	906	133	877	298	3096
	AVERAGES.	932	936	235	785	359	3248
Anthracite of Pennsylvania.	Beaver Meadow	923	982	1000	722	207	3834
	Forest Improvement	940	955	741	790	150	3576
	Peach Mountain	945	964	198	901	142	3150
	Lackawana	915	844	484	779	187	3209
	Lehigh	835	872	555	792	153	3207
	AVERAGES.	911	923	595	797	168	3395
Free-burning Bituminous of Pennsylvania.	Queen's Run	960	913	458	726	667	3724
	Blossbury	908	911	176	996	595	3586
	Dauphin and Susquehanna	873	835	171	766	602	3247
	Cambria County	863	860	172	867	250	3012
	Lycoming Creek	833	871	184	706	291	2885
	AVERAGES.	887	878	232	892	481	3299
Foreign Bituminous.	Newcastle, Eng.	809	776	191	827	595	3198
	Pictou, N. S.	792	738	97	928	588	3143
	Sydney, N. S.	747	669	276	764	424	2880
	Liverpool, Eng.	733	663	323	857	581	3157
	Scotch	649	625	107	847	521	2749
	AVERAGES.	746	694	197	844	526	3027
General Scale of Relative Values from the averages of Each Class.	Maryland Free-burning	1000	1000	395	880	682	
	Pennsylvania Anthracite	977	986	1000	893	319	
	Penn. Bituminous	951	938	390	1000	914	
	Virginia Bituminous	850	757	242	948	730	
	Foreign Bituminous	801	741	331	948	1000	

By inspecting this table, we see that Anthracites surpass the foreign Bituminous coals 20 per cent., when compared by equal weights, and 26 per cent., by equal bulks. In freedom from clinkerage, Anthracite stands pre-eminent; in rapid production of steam, when once in action, the Pennsylvania Bituminous coals are superior to all others; and, for the rapid generation of steam, the Foreign Bituminous coals are most efficient.

Coke.—Coke is a brittle, porous solid, of a greyish black color. It is artificially prepared by a process called coking, which consists in expelling the volatile matter from bituminous coal, and is usually carried on in ovens made of fire brick or stone. The coal is introduced at the top, and being lighted, a little air is admitted by openings in front. When the coal ceases to evolve smoking vapors, the supply of air is cut off, and the oven allowed to cool for a day or two. A door in front is then opened, and the coke is raked out while still hot. Water is thrown upon it to prevent further combustion. When coal of small size is used, water is sprinkled over it previous to firing, that the operation of coking may proceed more completely.

The quantity of coke obtained from a ton (two thousand pounds) of coal, varies from a thousand to sixteen hundred pounds, so that the coal sustains a loss of twenty to fifty per cent. of its weight. At the same time it increases in bulk nearly one fourth. The coke absorbs moisture from the atmosphere, sometimes to the extent of thirty per cent. It gives off no smoke in burning, and evolves a large amount of heat. It is extensively used in smelting metallic ores in those localities where anthracite cannot be obtained. It is also used in furnaces and fire chambers of locomotives, because no means have as yet been devised for effecting such a complete combustion of those hydro-carbons which are expelled in the process of coking, as to avoid the escape of large volumes of smoke. Could this be accomplished, we should save, not only the twenty to fifty per cent. of valuable heat-giving constituents of the coal, but also the expense of coking.

Peat as an Article of Fuel.—[1]The term *Peat* is applied to the organic matter or vegetable soil of bays, swamps, beaver meadows and salt marshes. It results from the decay of many generations of aquatic and marsh plants, as mosses, sedges, coarse grasses, and a great variety of shrubs, mingled with mineral substances derived from these plants, or blown and washed in from the surrounding lands.

How Peat is Formed.—In this country the production of peat from fallen leaves and decaying plants, depends on the presence of sufficient water to saturate these vegetable substances, and thus hinder the free access of air. Saturation with water also has the effect to maintain the decaying matters at a low temperature, and by these two causes in combination, the process of decomposition goes on very slowly. The solid products of such slow decay, are compounds that themselves resist decay, and hence they gradually form accumulations, sometimes of great extent. To that remarkable animal, the *Beaver*, we owe many of our richest peat bogs. These creatures, from time immemorable, have built their dams across rivers, thus flooding the adjacent forests. In the rich leaf mould at the water's verge, and in the cool shade of the standing trees, has begun the growth of the sphagnums, sedges, and various purely aquatic plants. These, in their annual decay, have shortly filled the shallow borders of standing waters, and, by slow encroachments, going on through many years, have occupied the deeper portions, aided by the trees, which, perishing, give their fallen trunks and branches toward carrying on the work. The trees decay and fall, becoming entirely converted into peat, or, as not unfrequently happens, retain their form, and, to some extent, their soundness.

Varieties of Peat.—The deposits of peat beds differ in color, some being grey; others, red; others, again, black. The majority, when dry, are of a dark brown or snuff color. They also vary remarkably in weight and consistency.

[1] Condensed from "Peat and its Uses," by Prof. Johnson, and "Facts about Peat," by T. H. Leavitt, Esq.

Some are compact and destitute of fibres or other traces of the vegetation from which they have been derived; these, on drying, shrink greatly, and yield tough, dense masses, which burn readily, and make an excellent fuel. Others, again, are light and porous, and remain so when dried; these contain intermixed vegetable matter that is but little advanced in decomposition. Some peats are almost entirely free from mineral matter, and, on burning, leave but few per cent. of ash. Others contain considerable quantities of lime, or of iron in chemical combinations, or of sand and clay that have been washed in from the adjoining hills. The accidental admixture of soil often greatly effects the appearance and value of peat, but, on the whole, it would appear that its quality is most influenced by the degree of decomposition which it has undergone. The fact that peat is fibrous in texture, shows that it is of comparatively recent formation, or that decomposition has been arrested before reaching its latter stages. Fibrous peat is found near the surface, but on penetrating farther, it is almost invariably found that the fibrous structure becomes less and less distinct, until, at a certain depth, it entirely disappears. It is not depth, simply, but age and advancement in decomposition, that determines these differences in texture. The *ripest*, most perfectly formed peat, that in which the decomposition has reached its last stages, which in Germany is termed *pitchy peat*, or fat peat, is dark brown or black in color, and comparatively dense and heavy. When moist, it is firm, sticky and coherent, almost like clay, and may be cut and moulded in any shape. On being dried, it becomes hard, and, on a cut or burnished surface, takes a lustre like wax or pitch.

Chemical Composition of Peat.—The process of burning demonstrates that peat consists of two kinds of matter, one of which, the larger portion, is *organic*, or vegetable, and is combustible; the other, smaller portion, is inorganic, or ash, and is indestructible by fire. Like that of the vegetation from which it originates, the organic part

consists of carbon, hydrogen, oxygen, and nitrogen. In the subjoined table are given the proportions of these elements, as found in several specimens of peat in various stages of ripeness:

	Crb'n.	Hyd'n.	Oxy'n.	Ntg'n.
1. Peat, porous, light brown,	50.86	5.80	42.57	0.77
2. " " red brown,	53.51	5.90	40.59	0.00
3. " heavy, brown,	56.43	5.32	38.38	0.00
4. " dark, red brown, well decomposed,	59.47	6.52	31.51	2.51
5. " black, very dense and hard,	59.70	5.70	30.04	1.55
6. " black, heavy, } best quality	59.71	5.27	32.07	2.50
7. " brown, heavy, } for fuel,	62.54	6.81	29.24	1.41

Varieties of Peat best adapted for fuel.—Only those kinds which can be cut out in the shape of coherent blocks or which admit of being artificially formed into firm masses, are of use in ordinary stoves and furnaces. The powdery or friable surface peat, which has been distinguished by frost and exposure, is ordinarily useless as fuel, unless it be rendered coherent by some artificial preparation. Unripe peat, which contains much decomposed moss, or grass roots, is too bulky to make an effective heating material before subjection to mechanical treatment. The best peat for burning is that which is most entirely free from undecomposed vegetable matter, and which is also free from admixture of earthy substances, in the form of sand or clay. Such peat is unctuous when moist, shrinks greatly in drying, and forms hard and heavy masses.

Peat is generally less efficient in the production of heat than wood, though having an equal, or greater proportion of carbon. The reason for this is found in the fact that it occupies a greater bulk for a given weight, a necessary result of its porosity. The best, or poorer qualities artificially condensed, may, on the other hand, equal or exceed the best kinds of wood in heating power, taken bulk for bulk. Another reason that renders some kinds of peat inferior to wood, in heating effect, is the great quantity of incombustible ash which it contains. Wood seldom has more than one and-a-half per cent of mineral matter, while some varieties of peat contain more than ten per cent. A

great drawback to the usefulness of many kinds of peat as fuel, lies in their friability. This property renders them incapable of transportation. Besides, when put into an ordinary stove or furnace, there can go on only a smouldering combustion, as would occur with cut tobacco or with saw-dust. A free burning fuel must exist in lumps or blocks which so retain their form and solidity as to allow a rapid draft of air through the burning mass.

Preparation of Peat by Machinery.—Numerous processes have been discovered for preparing peat. The efforts in this direction have met with abundant success, as regards the production of good fuel. The numerous inventions which have been made within the last fifteen years, with a view to improving the quality of peat fuel, as well as to expedite its production, have been directed to the following points: —

1. *Condensation* of the peat, to bring more fuel into a given space, thus making it capable of giving out an intense heat; at the same time increasing its hardness and toughness, making its transportation easier and more economical.

2. *Drying* by artificial heat, or reducing the amount of water contained by the peat, thus very considerably increasing its heating power.

3. *Charring.* Peat charcoal is as much better than peat for use, where intense heat is required, as wood-charcoal is better than wood.

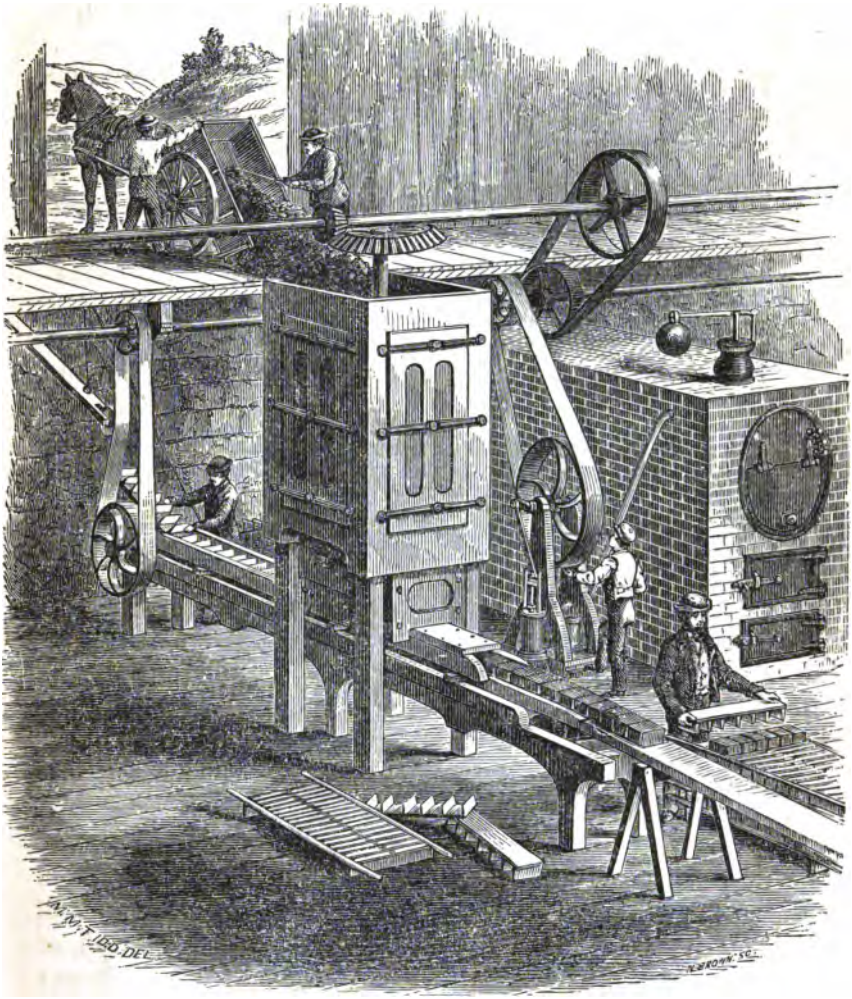
4. *Purifying* from earthy admixture, which is incombustible, and prevents free access of air to all parts of the mass while burning.

Our space permits us to notice only one of these inventions.

Leavitt's Peat Condensing and Moulding Mill. Mr. T. H. Leavitt, of Boston, has patented machinery which is in operation at East Lexington, Mass., at the works of the Boston Peat Company. The fresh peat is pulverized, or cut fine, moulded into blocks, and dried on light frames in the open air. The results claimed by Mr. Leavitt, indi-

cate that the machine is very efficacious. It consists principally of a strong box, or cistern, three feet in diameter, and six feet high, the exterior of which, with its gearing, is adapted to be driven by an engine of four horse-power.

FIG. 2.



LEAVITT'S PEAT CONDENSING AND MOULDING MILL.

The upper portion of the box is divided by a series of horizontal partitions, the upper ones being open lattice-work, and the lower ones perforated with numerous holes. The upright shaft which rotates in the centre of the box, carries a series of arms or blades, and as these revolve, they cut the peat and force it through the opening in the diaphragms. The lower portion of the box, in place of complete partitions, has a series of corrugated shelves, extending alternately from opposite sides, and the peat is compressed and scraped from these by arms adapted to the work. By these series of severe operations, the air-bubbles are expelled from the peat, and it is reduced to a homogeneous paste. When it arrives at the bottom of the box, it is still further compressed by the converging sides of the hopper, and is received in light moulds, which are carried on an endless belt.

The mill, it is asserted, will condense forty tons of crude peat daily, which, in Lexington, is estimated to yield from ten to fourteen tons of dry, marketable fuel. The cost of preparing this is less than two dollars per ton, while its present value is ten dollars per ton. It requires seven men, three boys, and two horses to dry, cart, mill, and spread the peat. The cost of the machine is six hundred dollars. The samples of peat there manufactured are of excellent quality. The drying is said to proceed with great rapidity, eight or ten days being ordinarily sufficient in summer season.

Peat Charcoal.—The common and simple mode of carbonizing or charring ordinary peat, is to arrange it in heaps, in the same manner as wood is piled for making charcoal, the sods or blocks must be regularly placed, and laid as compactly as possible. They should be about fifteen inches long by six broad, and six thick. The heaps, built hemispherically, should be smaller in size than piles of wood usually are. In general, some five or six thousand large sods compose the heap, which may contain fifteen hundred cubic feet. The mass must be allowed to heat more than is necessary for wood, and the process must be very carefully attended, on account of the extreme combustibility of the charcoal. The

quantity of charcoal obtained by this method is generally from twenty to thirty per cent. of the weight of dry turf. For many industrial purposes, however, the charcoal, so produced from peat in its natural state, is too light, because, generally speaking, it is only with fuel of considerable density that the most intense heat is produced. It is, therefore, only with peat in a solidified state that we can expect to prepare a charcoal thoroughly adapted as a fuel for the more severe processes required in the arts. By coking this, however, a charcoal is produced of a density of 1.040 or upwards, which is superior to the best wood-charcoal.

Peat in Europe.—At the Great Exhibition in 1855, numerous specimens of peat and peat-charcoal, prepared by different patent processes, were exhibited, which were remarkable for their density, and also for their cheapness. In the city of Paris, peat, moulded in small bricks, of sufficient density to sink in water, is supplied, for domestic purposes, from numerous sources. Peat, as an article of fuel, has, until recently, been used in this country only to a very limited extent, but in Europe it has been employed, both for domestic and manufacturing purposes, for several centuries. Dr. King, an Irish writer, in 1685 says of turf, "It is accounted a tolerably sweet fire; and having very impolitically destroyed our wood, and not as yet found stone-coal, except in a few places, we could hardly live without some bogs. When the turf is charred it serves to work iron, and even to make it in a bloomary, or iron-work. Turf-charcoal I reckon the sweetest and wholesomest fire that can be; fitter for a chamber and for consumptive people, than either wood, stone-coal or charcoal."

Peat used for Generating Steam.—Some experiments have been made in this country on the value of peat as fuel for locomotive and stationary boilers. One was tried on the New York Central R. R., Jan. 3, 1866. A locomotive, with twenty-five empty freight cars attached, on a cold day, with opposing winds, was propelled from Syracuse at the rate of sixteen miles an hour; the engineer reported

that the peat gave as much heat as wood, and burned with a beautiful fire.

Fluid Substances for Fuel.—There is a large number of inflammable fluids, which are distinguished from solids in that they burn on a wick, a property which renders them most convenient sources of heat for many purposes, though, by reason of their high price, they are seldom used, except for illumination, and where a small quantity of heat is required. They include alcohol, and the resinous oils.

Alcohol, when pure, consists of fifty-two and two-tenths parts of carbon, thirteen of hydrogen, thirty-four and eight-tenths of oxygen. It is a very convenient liquid for heating purposes, when a strong, concentrated heat is required. It burns with a bluish-white flame, emitting but little light, by reason of the comparatively small proportion of carbon which it contains. This, it will be noticed, is only a fraction over fifty-two per cent., while sperm oil, tallow and wax, contain nearly eighty per cent. of carbon.

Camphene, which is obtained by the distillation of the turpentine of the pine tree, differs from alcohol in its composition, in containing no oxygen. It is a pure hydro-carbon, consisting of eighty-eight and forty-six hundredths parts of carbon, to eleven and fifty-four hundredths parts of hydrogen. It is a superior heating and illuminating agent, but cannot be burned in common lamps without the escape of a dense volume of smoke. The reason for this will be given hereafter. Let it be noticed that, although camphene is a pure hydro-carbon, containing not an atom of incombustible matter, and burns with a whiter and more brilliant light than any other kind of fuel that we have mentioned, still, in the ordinary lamp, it is impossible to effect a complete combustion of its elements.

Petroleum.—Much interest has been excited in the public mind by the recent discoveries, in the United States and Canada, of very large accumulations of mineral oil, called *petroleum.* It is obtained in most instances from wells which are sunk by drilling through rock, often to the depth of sev-

eral hundred feet. Sometimes the oil rises to the surface from the pressure below, but generally it is pumped out by steam-power. It varies in color, some kinds being of a greenish, others of a reddish hue. It is mingled with brine and water, and, when purified, yields from thirty to ninety per cent. of light oil fit for burning.

This oil is rich in carbon, and, like camphene, requires to be burned in lamps especially adapted to its use. The abundant supply has reduced its price, so that it is now extensively used for heating and culinary purposes, and even for the production of steam.

In Birmah, petroleum is mixed with earth or ashes, and used for fuel. It also affords both light and fuel to the inhabitants of Batku on the Caspian.

Chemical Analysis of Wood and Coal:

		C'rb'n.	Hyd'n.	Oxy'n	Ntg'n.
Wood.	Hard,	49.45	5.50	44.20	0.85
	Soft,	48.50	6.70	43.94	0.86
Coal.	Anthracite,	89.50	1.75	4.20	0.00
	Bituminous,	82.20	5.50	9.30	0.00
	Cannel,	80.49	11.24	6.73	0.87
	Asphaltic,	82.67	8.14	8.19	0.00
	Lignite,	72.30	5.30	2.24	0.00
	Peat, (best quality),	59.00	5.27	32.07	2.50

The table here given shows the proportions of the constituent elements, exclusive of the earthy matter, or ash, which, in good coal, does not exceed 10 per cent. This consists chiefly of silica and alumina, in the ratio of ten of the former, to one or two of the latter, with some traces of lime and magnesia; and the red ash coal contains oxide of iron, derived from iron pyrites.

Estimation of the Calorific Power of Fuel.

The quantity of heat developed by the combustion of a given amount of fuel, can be determined only relatively. Though, by experiment, we find that 1 lb of wood, under the most favorable circumstances, will raise thirty-seven pounds of water, from 32° to 212°, yet no idea, from this result, can be

formed of the absolute quantity of heat evolved; but if we find, by the burning of a pound of charcoal, that the temperature of 74 pounds of water is raised the same number of degrees, it follows that the heat-giving power of wood is to charcoal as 37 to 74, or as 1 to 2. In this way the quantity of heat may be *relatively* measured with a tolerable degree of accuracy.

The best experiments ever made, to determine directly the relative heating power of fuel were those conducted by Marcus Bull. He constructed one chamber within another, and, while the outer apartment was maintained at a uniform temperature, the inner one was kept, by the combustion of the fuel, 10° higher. The comparative lengths of time, during which the temperature of the inner chamber was maintained 10° higher than the outer, show the relative heating value of the fuel tried.

The following table comprises the results of those extensive and valuable experiments on some of the more common varieties of fuel.

	Specific quantity of dry wood.	Avoirdupois pounds of dry wood in one cord.	Products of charcoal from 100 parts of dry wood by weight.	Specific quantity of dry coal.	Pound of dry coal in one bushel.	Pounds of charcoal from one pound of dry wood.	Bushels of charcoal from one cord of dry wood.	Time 10° of heat were maintained by the combustion of a pound of each article.	Heating value of specified quantity of each article—Shell-bark Hickory=100
								H. M.	Cord.
1. Shell-bark Hickory,	1.000	4469	26.22	0.625	32.89	1172	36	6–40	100
2. White Oak,	0.855	3821	21.62	0.401	21.10	826	39	6–20	81
3. White Beech,	0.724	3236	19.62	0.518	27.26	635	23	6–00	65
4. Black Birch,	0.697	3115	19.40	0.428	22.52	604	27	6–00	63
5. Hard Maple,	0.644	2878	21.43	0.431	22.68	617	27	6–10	60
6. Soft Maple,	0.597	2668	20.68	0.370	19.47	551	28	6–00	54
7. Yellow Pine,	0.551	2463	23.75	0.333	17.52	585	33	6–30	54
8. White Birch,	0.530	2369	19.00	0.364	19.15	450	24	6–00	48
9. Hard Pine,	0.426	1904	26.76	0.298	15.68	510	33	6–40	43
10. Chestnut,	0.522	2333	25.29	0.379	19.94	590	30	6–40	52
									Tons.
11. Lehigh Coal,				1.494	78.61			13–10	99
12. Susquehanna Coal,				1.373	72.25			13–10	99
									100 bush
13. Cannel Coal,				1.240	65.25			10–30	230
14. Scotch "				1.140	59.99			9–30	191
15. Oak Charcoal,				0.401	21.10			15–00	106
16. Pine Charcoal,				0.285	15.00			15–00	75
17. Coke,				0.557	29.31			12–50	126

Remark.—Since writing the article on the "utility of forests" (Vide. page 22), we have been informed that the subject of preserving the magnificent forests of Michigan is engaging the attention of the Legislature of that State. Its forest-wealth, once greater than that of any other State, is tributary to so many lumber markets, that it is rapidly disappearing. Such vast tracts have been stripped that climatic changes, injurious to vegetation, have been induced. Crops have been deteriorating for several years, and it is now believed that this is owing to the despoliation of the woodlands; the increasing severity of winters, by which forest-trees have been killed, and the diminution of fertilizing rains are also attributed to this cause. From the clearing of so large a section of timbered lands, the cultivated districts have been exposed to the ravages of blighting winds. The loss to the wheat-crop in one winter from this cause is estimated at $5,000,000. It is proposed to mitigate the evil by exempting forests from taxation, and by other effective measures.

CHAPTER IV.

The Elements of Matter and the Laws of Chemical Combination.

Combustion a Chemical Process.—It has already been stated that heat, for the generation of steam, and for household purposes, is the result of chemical action which takes place between oxygen and certain elements found in such organic substances as wood, coal, peat, and other varieties of fuel. This process is termed the *burning*, the *consuming*, or the *combustion* of fuel. Call it by what name we will, it is a *chemical* process, and therefore whatever pertains to its investigation lies strictly within the department of chemistry. The subject involves a consideration of the nature and properties of the various kinds of coal and wood, and examines the chemical action of their several constituents upon each other. It investigates a very difficult branch of chemistry, that of gaseous formations, and their complex proportions, combinations and equivalents. It involves the closest observation of the separate influence which each element of the atmosphere exerts on combustible bodies in the process of combustion. The burning of a single grain of bituminous coal involves a greater number of distinct natural phenomena and chemical results, than almost any other process within the range of chemical science. And it is only by close scrutiny and patient investigation that we are able to unveil the mysteries of nature, gain access to her laboratories, discover her laws, and thus become familiar with her methods of operation, so as to

secure the most important results. Let not the practical man, who reads these pages, be alarmed at such terms as *oxygen, nitrogen, equivalent, combining number, &c.* Let him not suppose that he can dispense with a knowledge of these, if he would learn anything of the combustion of fuel. Without such knowledge he is at the mercy, and becomes, too often, the victim of every speculative, smoke-burning quack, who neither understands nor appreciates the beautiful exactness and efficiency of nature's processes. It would be no more absurd for a child to try to read, without knowing a single letter of the alphabet, than for a man to attempt to gain correct notions respecting combustion, without first becoming familiar with the elements employed, and the laws which govern their action upon each other. If the reader be not already familiar with these, let this and the following chapter be a brief introduction.

If the heat from fuel is due to chemical action, the first question to decide, in entering upon an investigation of this subject, is: *What is chemical action;* under what circumstances does it occur; on what conditions does it depend; what laws, if any, control it? But it is chemical action between *oxygen* and certain *other elements.* The second question, then, to be considered, is: *What is oxygen;* where and how may it be obtained; what are its properties; what part does it play in combustion? Our third inquiry should be, *what are these other elements;* what are their qualities, and what office do they perform?

Chemical Action.—Whatever occupies space, whatever affects our senses, is known as *matter.* A limited portion of matter is called a *body.* Bodies are capable of undergoing three kinds of change,—change of place, change of form, and change of nature. A piece of marble may be taken from the quarry, transported any distance, and wrought into a beautiful statue. This would be change of place and form, but the nature of the marble would be still unchanged. Its crystaline structure would be the same in the statue as in its native bed. These are *mechanical* changes. If we should

take the same piece of marble, and subject it to a high degree of heat, its *nature* would be changed; it would be separated into lime and carbonic acid, neither of which resembles marble.

Chemical Action, therefore, is a term used to designate all those processes, by which the nature of bodies in respect to form, color, taste, smell, and action upon other bodies, is changed, so that new substances, unlike the old, are formed. Thus, wood exposed to the air for a long time, decays; that is, its organic structure is broken up, and its elements converted into new substances; so iron is changed to iron-rust; the juice of the grape turns to wine; fuel in the stove wastes away.

Chemistry has shown that the solid crust of the globe, all the living beings upon it, and the atmosphere which surrounds it, are composed of sixty-four or sixty-five elements.

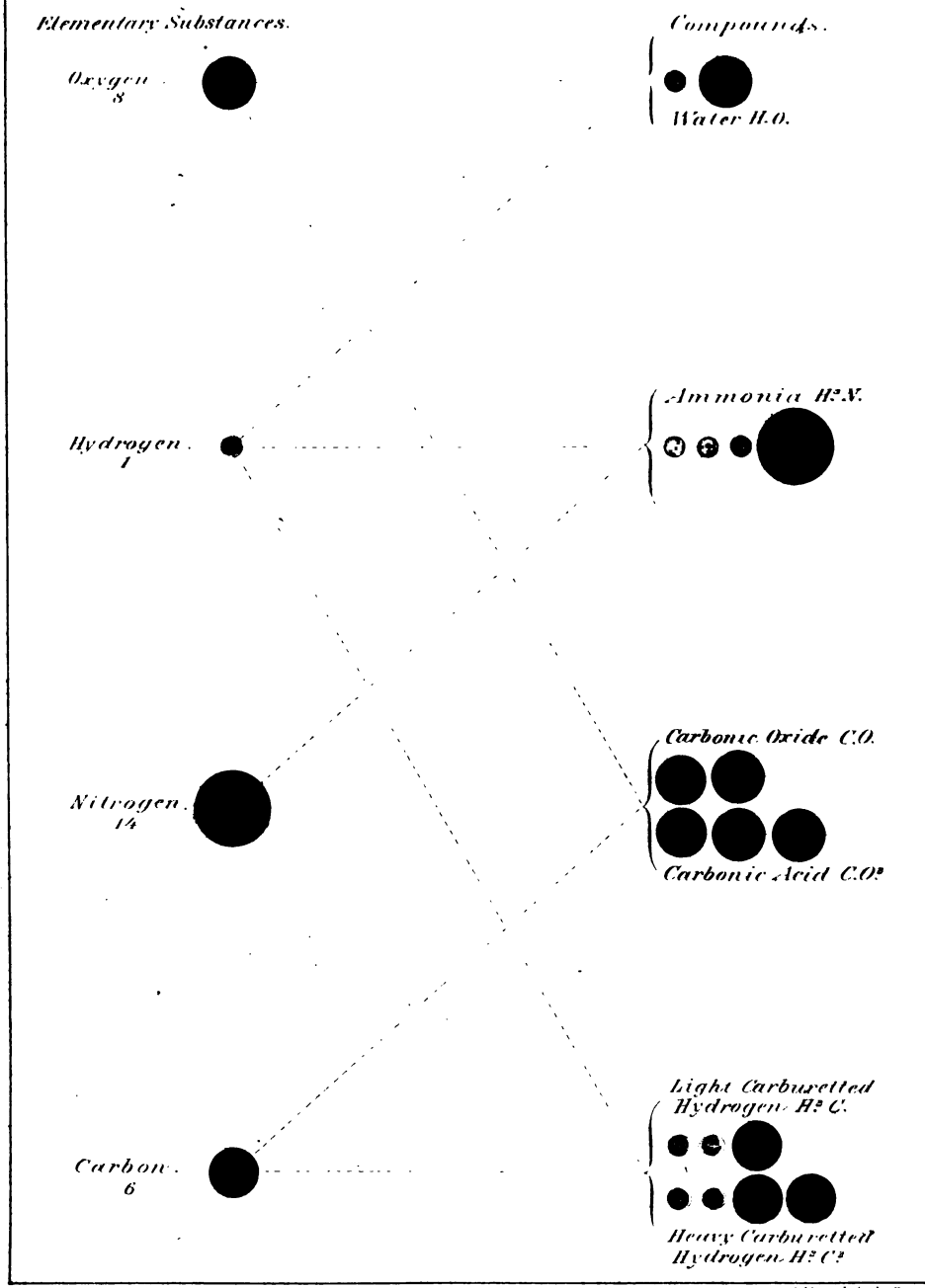
An element, or simple body, is a substance which has never been derived from, nor resolved into, any other kind of matter. Thus silver and gold, oxygen and nitrogen, are called elements, because no force, at our command, has, as yet, been able to separate them into other bodies.

A compound body is one that can be separated into two or more elements. Marble, for example, may be resolved, by the application of heat, into quicklime, and an invisible gas. Water may be separated into two colorless gases,—hydrogen and oxygen. Hence these are called compound substances.

Classes of Elements.—Elements are of two kinds, *proximate* and *ultimate*. A compound body may be made up of compound bodies. The lime and the carbonic acid of which the marble is composed, are themselves both compound, and hence, these are only the *proximate* elements of the marble, but after the lime has been resolved into calcium and oxygen, and the carbonic acid into carbon and oxygen, our analysis ceases. We cannot decompose the calcium, the carbon, the oxygen; hence, we call these the *ultimate* elements of the marble.

Diagram 1.

Elements employed and compounds formed in the process of Combustion.



Atwood, del. Meisel, Lith. Boston.

Of the sixty-four or sixty-five ultimate elements found in nature, four are employed in the combustion of fuel, oxygen, hydrogen, nitrogen, and carbon. Of these a more particular description will be given hereafter.

Explanation of Diagram, Illustrating the Laws of Chemical Combinations.

Use of Diagrams.—Since many important elements and compounds, found in nature, are invisible, a clear conception of their existence, properties and relations, is rendered somewhat difficult. But, whenever such invisible substances possess qualities, fixed and clearly defined, which are capable of being represented to the eye, diagrams prove a very efficient means of conveying distinct impressions of them to the mind. By the use of these diagrams, we are able to bring before the eye the relation of atoms, the more important properties of the elements, the structure of compound bodies, and the numerical laws of quantity, which govern, with unerring accuracy, all chemical combinations.

The illustrations here given are limited to those elements and compounds which are employed in the combustion of fuel.

In Diagram 1, the name of the elements are given in the left-hand column. Opposite each name is a colored circle, designed to represent the elements. The color given to each circle illustrates one or more properties peculiar to that element. Thus oxygen is the grand agent for carrying on the process of combustion, and as *red* is the most common representative of fire, we assign this color to all those circles standing for oxygen.

All those varieties of fuel which contain any considerable proportion of hydrogen, burn with a yellowish flame, as wood, bituminous coal, etc., hence this element is appropriately represented by *yellow* circles.

Nitrogen constitutes four-fifths of the atmosphere, which, when seen in large quantities, appears *blue*, therefore this

color is given to the circles representing *nitrogen*.

Carbon is shown by *black* circles. This is its natural color as seen in graphite (improperly called black lead), and in the different varieties of coal.

Manner in which Substances enter into Chemical Union.

In Diagram 1, the colored circles on the right represent compounds formed from the elements on the left. The lines passing from single circles on the left, and converging to the right, indicate,—

Chemical Affinity, which is the attractive force exerted between the atoms of unlike substances at insensible distances, causing them to unite and form compounds possessing new and distinct properties. Of the cause or real nature of this and other forces, we possess no absolute knowledge. They are types of spiritual existence, and we are as firmly convinced of their reality as of the reality of our own existence, since they are clearly recognized by their effects upon matter. A stone thrown into the air falls to the ground. This movement is ascribed to the attraction of gravitation, a force which is constant and universal in its action upon all matter.

Cohesion is the attractive force which exists between similar particles at insensible distances, binding them together in one uniform mass, as a piece of wood, iron or coal.

Chemical Affinity is more restricted in its action, and is modified by various circumstances.

1st. It occurs only between the atoms of *dissimilar* substances. Two pieces of iron, or a piece of iron and one of copper, placed in contact, manifest no disposition to unite with each other, while *unlike* substances, as iron and sulphur, potassium and oxygen, may exhibit the most energetic kind of chemical affinity.

2d. In general, the *more unlike* any two substances are, the stronger is the chemical affinity between them. The metals, as a class, possessing many properties in common, show but a feeble tendency to unite with each other. Two alkalies,

as soda and potash, will not enter into chemical union. Nitric acid may be mingled with sulphuric acid in any proportions, no change of character is effected, the mixture is acid still. But if an acid is brought in contact with an alkali, as nitric acid with potash, they will combine and produce nitrate of potash, (saltpetre,) a neutral salt, possessing neither acid nor alkaline properties.

3d. Chemical affinity acts only between atoms removed from each other at insensible distances, thus requiring an *intimate mixture or incorporation* of the atoms to bring them within its range. Thus tartaric acid and carbonate of soda will not unite while dry, but if a portion of water be added to dissolve both, and to leave the particles free to move among each other, that they may be brought into close contact, they will readily combine.

4th. Elements exhibit a far greater inclination to unite at the moment *when liberated* from some previous combination. Substances in this condition are said to be in a *nascent* state, (from the Latin *Nasci*, to be born.) Thus nitrogen and hydrogen will not, under ordinary circumstances, combine, when mingled in the same vessel, but when liberated from some other chemical combination, as during the putrefaction of animal matter, they unite to form ammonia. The same compound is also formed in the furnace during the process of combustion, when hydrogen is allowed to escape and mingle with the nitrogen, which is always present in great abundance.

5th. Every direct chemical union is attended by the *liberation* of heat, and generally of light The amount of heat evolved is in proportion to the rapidity of the chemical action. If iron be exposed to the air, oxygen will slowly unite with it, and produce the oxide of iron (iron rust.) In this case, heat is given off, but so gradually as to be imperceptible. While if a few drops of sulphuric acid are brought in contact with chlorate of potash, the chemical action is so rapid that sufficient heat is evolved to cause the whole mass to burst into flame.

6th. All compounds formed by the action of chemical affinity, possess properties *unlike* those of their constituent elements. Chlorine, a suffocating gas, and sodium, a bright, shining metal, unite, and give us common salt. The bluish-white metal, mercury, and the yellow metalloid, sulphur, combine and form the bright red paint known as vermilion. And sulphur, uniting with the black, solid carbon, produces a clear, colorless liquid, the bi-sulphide of carbon.

7th. The power exerted by chemical affinity is wonderful beyond description. An iron wire which will sustain a weight of several hundred pounds, will readily yield if brought in contact with diluted sulphuric acid. A silver coin thrown into nitric acid, will have its atoms torn asunder, and in a short time will be completely dissolved. And the force of the chemical affinity between the atoms of a pound of hydrogen and eight pounds of oxygen, is estimated to be equal to a mechanical force sufficient to raise forty-seven million pounds to the height of one foot.

8th. Chemical affinity unites substances only in definite proportions, and since these are unalterable, the relative proportions of the constituent elements in any compound, may always be expressed by numbers. Water, for example, at the equator or the poles, as rain, snow, ice, or vapor, is uniformly composed of eight parts, by weight, of oxygen, and one part of hydrogen. The truth of this may be established both by analysis and synthesis. When, under favorable circumstances, a current of electricity is passed through water bubbles of gas will escape from each pole of the battery. On examination, the bubbles from the positive pole will prove to be pure oxygen, and those from the negative pole, pure hydrogen. And there will always be eight parts, by weight, of the former, to one of the latter. Again, water, when artificially prepared by burning hydrogen in oxygen, requires just eight pounds, ounces, or grains of oxygen, for one pound, ounce, or grain of hydrogen. If nine grains of oxygen be taken, one grain will remain uncombined; or if two grains of hydrogen be used, one grain will also be left

free. This law is absolute. The union of these elements to form water, will always take place in this proportion, and in no other. So lime is always found to be composed of eight parts of oxygen and twenty parts of calcium; common salt, of thirty-five parts of chlorine and twenty-three of sodium; potash, of thirty-nine parts of potassium, and eight of oxygen; and thus with all other chemical compounds.

Law of Multiple Proportions.

Many of the elements have the power of combining with each other in more than one proportion. Thus, by looking at the column of compounds in Diagram 1, we notice that carbonic acid contains a double proportion of oxygen.—But this is no contradiction of the statement that chemical affinity unites substances only in fixed proportions. For it will always be found that the larger proportion have a definite ratio to the smaller, being an exact multiple of it. If carbon, or any other element, unites with more than eight parts of oxygen, it will invariably unite with some multiple of eight parts, as sixteen, twenty-four, etc. And the same principle applies to every chemical combination.

This numerical law, universally applicable, as it is, enables us to lay out before the eye the relative proportions of the elementary substances entering into any compound. We find that hydrogen combines with other elements in the smallest proportion of any known substance, hence we take this as the standard with which to compare the combining quantity of every other element. This subject may, perhaps, be more clearly illustrated by the case of a merchant who wishes to count out a certain sum of money, taking half its value in silver, and half in gold. He will be obliged to take fifty ounces of silver for every three ounces of gold. In this case, fifty ounces of silver would be *equivalent* to three ounces of gold. So in chemical compounds. There is as much chemical energy in one grain of hydrogen as in eight grains of oxygen, that is, they neutralize or balance each other, so

that if we assume the equivalent, or combining number of hydrogen, to be 1, that of oxygen will be eight, that of carbon 6, since it requires six grains of this element to combine with one grain of hydrogen; that of nitrogen 14, for a like reason, and so on. And if we represent hydrogen by a circle of a given size, a circle eight times as large will represent oxygen. These placed side by side, as in Diagram 1, illustrates the true composition of water. A circle six times as large as that assigned to hydrogen will represent carbon, and one fourteen times as large, nitrogen; the number below the name of each element represents the equivalent or combining member of that element.

Combination by Volume.—Of the four elements employed in the combustion of fuel, three are gases, as are also their compounds. It will be more convenient to deal with these by measure than by weight, and it will be found that gaseous bodies always combine with each other in fixed and definite volumes, though these volumes may not have the same ratio to each other as the corresponding equivalents by weight. Thus the equivalent of oxygen is 8. We place eight grains of oxygen in a jar which will contain exactly this quantity. The equivalent of hydrogen is 1, but we find the jar which held one equivalent, or eight grains of oxygen, will hold only half an equivalent, or one-half grain of hydrogen. Therefore the equivalent volume of hydrogen is exactly double that of oxygen, while its equivalent weight is only one-eighth that of oxygen. Again, the equivalent of nitrogen is 14, and we shall find on trial that the jar will contain but half an equivalent of this gas; hence, the equivalent volume of nitrogen is the same as that of hydrogen. The volume of two gases after combination, is often less than the sum of their volume in their separate state; or, in other words, two gases, by their chemical union, suffer a condensation. Two measures of hydrogen and one of oxygen, for example, form only two measures of steam. All the diagrams in this treatise, with the exception of No. 1, will represent the relations and combinations of the different ele-

ments by volume, instead of by weight; but hydrogen will still be the unit of measure.

Atoms.—The laws of combining proportions which have thus far been explained, are the results of actual experiments, independent of all speculation. They are the expression of facts, established by direct and repeated observation, and may be verified at any time, by carefully analyzing a few chemical compounds, such as water, marble, or common salt. But the human mind is never satisfied with a knowledge of bare facts. It seeks to ascertain the hidden causes which lie *beyond the sphere of observation* and experiment. For the remarkable phenomena displayed by that affinity which unites *chemical* substances in the manner we have seen, there *must* be a cause. There *must* be some cause which makes it impossible for elements to combine in any other than these definite proportions.

The chemist has numerous and powerful reasons for believing that all matter is composed of atoms, that is, of exceedingly minute, unchangeable particles. It has been objected that we cannot conceive of particles so small that, if possessing weight and figure, they may not be divided into still smaller quantities. Granting this, chemists, nevertheless, are compelled to assume that Nature does ultimately limit the divisibility of matter. It is not insisted that, *in theory*, atoms are incapable of division, only that *practically* they are so. Every atom may, perhaps, consist of numerous smaller atoms, but *physically* it is considered indivisible and unchangeable. We may compare these ultimate atoms of matter, to merchandize put up in certain forms, which in commerce are never divided or broken open. Thus many kinds of goods pass through a dealer's hands, sealed up in parcels, cans, or boxes, which the merchant never opens. In practical commerce they are *indivisible*, though absolutely they are not so. All matter is believed to be composed of ultimate, indivisible, imperishable atoms, endowed with cer-

[1]From Youman's Atlas of Chemistry.

tain determinate properties which we can neither alter nor destroy. The visible objects of nature are viewed as being formed by the close arrangements of these atoms, as a massive edifice is built by placing together a great number of hewn stones, or moulded bricks. Being solid, and incapable of separation, these particles do not fuse, or run into larger particles, as would be the case with two drops of a liquid metal, like mercury, placed in contact with each other, but under the influence of various constraining forces, as cohesion, affinity, or electric power, they arrange themselves side by side, in groups. Assuming that all matter is thus composed of associated atoms, the atomic theory, as it is called, teaches:—

1st. That all atoms of the same element possess exactly the same weight.

2d. That atoms of different elements may possess different weights.

3d. That the number indicating the weight of an atom of any element, is the same as the combining number, or equivalent, for that element.

Thus, for the vague conception of abstract proportions, we substitute the distinct idea of a solid, ponderable atom. Its weight, compared with that of other atoms, is its combining number. Upon every atom of hydrogen, the number 1 is considered to be stamped, as if the whole amount of hydrogen existing in the universe, had been coined at the same mint, into pieces of the same value. In like manner, all the atoms of carbon bear the mark of 6; those of oxygen, 8; those of nitrogen, 14.

Such advantages does this theory offer, both in the acquisition and retention of chemical knowledge, that it has been universally adopted. The mind grasps more readily the conception of solid particles, than of abstract numerical ratio. Hence the language of the atomic theory is in current use. We employ the term *atom*, rather than *proportion;* and *atomic number*, rather than *combining number*, or *equivalent.*

Recapitulation.

An element, or simple body, is one that *cannot* be decomposed.

A compound body is one that *can* be decomposed.

The elements employed in the process of combustion are oxygen, hydrogen, nitrogen, and carbon.

These elements are represented, in this treatise, by circles of different colors; oxygen, by red; hydrogen, by yellow; nitrogen, by blue; and carbon, by black.

The force which draws the elements together to form new substances is called *Chemical Affinity*, and is represented in Diagram 1, by lines passing from the left, and converging toward the right.

Chemical affinity acts only on the atoms of dissimilar substances, and requires that these be at insensible distances from each other, hence the more perfect their intermixture, the more rapid will be the chemical action between them.

The more unlike any two elements are, the stronger will be their affinity for each other.

Every chemical union is attended by the evolution of heat, and generally of light.

The quantity of heat evolved will depend on the rapidity and intensity of the chemical action.

Every chemical compound possesses properties unlike those of its constituent elements.

All elements, whether proximate or ultimate, enter into chemical union only in fixed and definite proportions.

The numbers expressing these proportions are called equivalents or atomic weights.

CHAPTER V.

Physical and Chemical Properties of the Elements Employed in Combustion.

Oxygen.—Of the elementary substances with which modern chemistry has made us acquainted, oxygen is the most important and the most widely diffused. It constitutes, by weight, one-fifth of the atmosphere, eight-ninths of all the water on the globe; four-fifths of all vegetable and three-fourths of all animal substances; and nearly one-half the solid crust of the earth.

Pure oxygen may easily be obtained by selecting any of its compounds that will readily part with it, as, for example, the red oxide of mercury. In this compound, the affinity between the oxygen and the mercury is so feeble that a very moderate degree of heat will destroy it, and the oxygen will be set free, and may be collected for examination, while the mercury will be found in small globules, on the sides and bottom of the vessel.

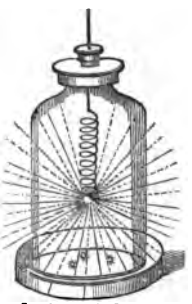
Properties of Oxygen.—Oxygen is a colorless gas, tasteless, and destitute of odor. No degree of pressure or cold has ever reduced it to a solid or even to a liquid state. It is about one-tenth heavier than common air, (specific gravity 1.1057), and it forms about twenty-three per cent. of the atmosphere. One hundred cubic inches of it weigh nearly thirty-four and one-fifth grains.

Oxygen is a neutral substance, possessing neither acid nor alkaline qualities, but, though apparently weak and inert, it is endowed with the most remarkable properties.

Affinity for other Elements.—Oxygen possesses the widest range of affinity of any known substance. It combines with all the other elements except fluorine, though its affinity for other substances varies widely according to circumstances. At ordinary temperature it unites slowly with most of the metals. A piece of iron exposed to the oxygen of the air is attacked by it, and will be converted into the oxide of iron,—a process called oxidation—but here the action is very gradual; with copper and many other metals it is still more so. A stick of wood may remain for years exposed to the action of oxygen, and yet undergo but a very slight change; but when at a high temperature, oxygen seizes upon these substances with a terrible energy, as the following experiments will show.

Iron and other Substances Burning in Oxygen.—Take a piece of fine iron wire previously coiled in the form of a spiral; fasten to one end a bit of charcoal; heat this in the flame of a lamp until it glows; then plunge it into a jar of pure oxygen. (Fig. 3.) The instant the heated iron comes in contact with the oxygen, the slumbering energies of chemical affinity are called into activity. The wire burns with an intense, white light, throwing out in every direction beautiful star-like scintillations of dazzling brightness. Oxide of iron is produced, which may be seen at the bottom of the jar. So intense is the heat produced by the union of the atoms of oxygen with the atoms of iron that melted globules of the oxide fly off and remain red hot for some time under water, and not unfrequently fuse deeply into the glass upon which they strike. A lighted candle, or piece of wood, lowered into a jar of oxygen, burns with great intensity, and an extinguished candle, which has the least spark of fire remaining, will

FIG. 3.



Iron Burning in Oxygen.

be instantly re-kindled on entering the jar, and will burn with intense brilliancy. In this way, a candle may be relighted more than fifty times, in a jar containing less than a quart of oxygen.

FIG. 4.

Sulphur Burning in Oxygen.

If a small piece of sulphur be placed in a metallic cup, and ignited in pure oxygen, (Fig. 4) it burns with a beautiful blue flame, and forms sulphurous acid.

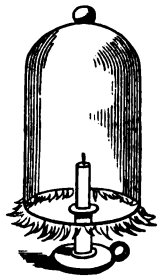
Oxygen has a powerful affinity for all those elements called *combustible;* and many, which are regarded as *incombustible*, burn with great violence when exposed to it, as in the case of the iron wire. If this element were not largely diluted with the neutral element, *nitrogen*, our whole globe would be enveloped in the flame of a general and most terrible conflagration.

Hydrogen.—This element is never found free, in nature. The substance which contains it in greatest abundance is water, of which it constitutes one-ninth part, by weight. In the mineral kingdom it is not very abundant, but it enters largely into the composition of various kinds of wood, and is always present, in greater or less abundance, in the different varieties of mineral coal.

How Obtained.—Hydrogen, for purposes of experiment, is usually obtained by the decomposition of water. If strips of zinc be thrown into a jar containing water, a portion of the water is decomposed, the oxygen seizes upon the zinc, and converts it into oxide of zinc, and the hydrogen is set free. Very soon, however, the zinc becomes coated with the oxide, and the operation ceases. But if sulphuric acid be added, to dissolve the oxide, so as to expose fresh surfaces of zinc to the action of the water, a constant supply of hydrogen may be obtained.

Properties of Hydrogen.—Hydrogen is an invisible and, when pure, a tasteless and inodorous gas. It is the lightest of all known substances, being one sixteenth as heavy as oxygen, and less than one-fourteenth as heavy as air. One hundred cubic inches of it weigh only two grains. Hydrogen is highly inflammable, but will not support combustion. A lighted taper introduced into a jar filled with it, is immediately extinguished, but the hydrogen itself takes fire, and burns at the mouth of the jar (Fig. 5) where it comes in contact with the oxygen. They unite, in the proportion of two volumes of hydrogen to one of oxygen, forming water in the state of an invisible vapor.

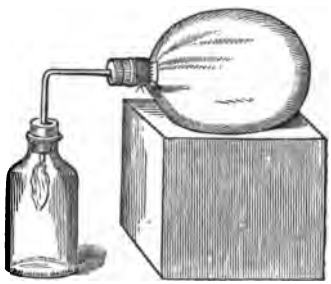
FIG. 5.



Hydrogen Extinguishing a Candle.

How Hydrogen Burns.—Pure Hydrogen burns with scarcely any light, but evolves an intense heat. Fill a gas bag with pure hydrogen, and pass a small stream of the gas through a tube into a jar of oxygen, (Fig. 6,) on being ignited, it burns with a feeble flame. The inside of the jar is soon covered with a misty dew, and if the experiment be prolonged, drops of liquid will finally trickle down the sides to the bottom of the jar. When examined, this liquid is found to be water. It has been produced from the chemical union of the hydrogen and oxygen.

FIG. 6.



Hydrogen burning in Oxygen.

If hydrogen be thoroughly mixed with oxygen in the proportion of two parts, by volume, of hydrogen, to one of oxygen, and then ignited, combustion will occur simultaneously throughout the whole mass, and will be attended by

a violent explosion. This may be illustrated by filling a gas bag, and inflating a soap bubble with the mixture. On account of the levity of the hydrogen, the bubble will ascend like a balloon. On being fired, it explodes with a loud report.

FIG. 7.

Explosion of Mixed Gases.

If a quantity of these bubbles be blown up in a shallow dish, (Fig. 7,) and a match applied, the instantaneous union between the atoms of the two gases is accompanied by a very sharp and loud report. If, instead of two parts of hydrogen and one part of oxygen, five parts of air and two of oxygen be used, the explosion will be much less violent. A mixture of hydrogen and oxygen, or of hydrogen and common air, will never unite under ordinary pressure, and at ordinary temperature.

Nitrogen.—Nitrogen is very extensively diffused throughout nature. It forms about four-fifths of the atmosphere, enters largely into the animal and vegetable kingdom, and is found in small quantities in some varieties of coal.

FIG. 8.

Preparing Nitrogen.

How obtained.—Nitrogen may be obtained by withdrawing the oxygen from a portion of the air. If a bit of phosphorus, placed in a cup and floated in a shallow dish partly filled with water, be set on fire, and a jar be placed over it, (Fig. 8,) the phosphorus will take the oxygen from the air within the jar, forming phosphoric acid, which the water rapidly absorbs, leaving the nitrogen free.

Properties of Nitrogen.—This gas, like oxygen and hydrogen, is invisible, odorless, and tasteless, but, *unlike* them, it is noted for its inertness. It combines directly with no other element, and is therefore neither combustible, nor a supporter of combustion. A lighted taper introduced into a jar of this gas is immediately extinguished, nor will the

gas itself take fire, as is the case with hydrogen, when it comes in contact with the atmospheric air. It is a little lighter than common air; if a given volume of air weighs one thousand grains, the same volume of nitrogen will weigh nine hundred and seventy-one grains. Its chief use in the atmosphere is to dilute the oxygen, and subdue the terrible energy of this wonderful and awe-inspiring element to an innumerable variety of useful purposes.

Carbon. This element, which forms the solid basis of most fuel, is among the most abundant and most important of the elementary substances. It exists in nature under a variety of conditions. The diamond is carbon in its purest state, as may be proved by burning it with oxygen, when pure carbonic acid *only* is produced.

Charcoal and coke are well-known forms of carbon. The former is obtained from wood; the latter from coal.

Properties of Carbon.—Carbon, at ordinary temperature, has little or no affinity for other elements, and is consequently one of the most unchangeable of all known substances. Grains of wheat charred in Herculaneum nearly two thousand years ago, still retain their form. At high temperature, however, carbon surpasses all other elements in its affinity for oxygen, and upon this property depends the important part which it plays in the process of combustion of fuel.

If a small piece of charcoal (nearly pure carbon) be heated to redness, and lowered into a jar of oxygen, (Fig. 9) it will glow with an intense, white light, waste away, and disappear. An important fact to be kept in view in the burning of carbon is, that while an intense heat is given out, *no flame is produced.*

FIG. 9.

Carbon burning in Oxygen.

Phosphorus and Sulphur.—There are two other elementary substances which claim a brief notice, as we shall have occasion to refer to certain properties possessed by them. These are Phosphorus and Sulphur. The former

is a soft, colorless, semi-transparent, waxy solid, highly inflammable, bursting into a brilliant flame at low temperature, and burning with great violence. If a small piece of phosphorus be placed in a small metallic cup, (Fig. 10,) and lowered into a jar of oxygen, no rapid chemical action will follow, but if the phosphorus be touched with a piece of heated wire, it will instantly kindle and burn with great intensity, giving out a light too brilliant to be endured by the eye. By reason of its inflammability it is kept under water; if exposed to the air, it slowly oxidizes. Its chief use is for the manufacture of friction matches. For this purpose it is mingled with glue and other substances, as otherwise it would take fire by the least friction, or even by exposure to the rays of the sun.

FIG. 10.

Combustion of Phosphorus in Oxygen.

Sulphur.—This is found in great abundance in volcanic regions, in coal, and in some species of plants. It is a light solid, brittle, and, like phosphorous, very inflammable, taking fire at a low temperature. It burns with a beautiful flame, and forms sulphurous acid, a gas possessing a pungent, suffocating odor, which may be readily recognized on lighting friction matches, for the manufacture of which, like phosphorous, it is extensively employed.

Compounds of Oxygen, Hydrogen, Nitrogen, and Carbon.—These four elements enter into combination with each other, and give rise to a large class of compounds, some of which act a prominent part in the process of combustion. These are carburetted hydrogen, and bi-carburetted hydrogen.

Nature of these Gases.—Carburetted hydrogen is composed of one equivalent of carbon and two of hydrogen, (by weight 6 parts of carbon and 2 of hydrogen.). This is a colorless, odorless, tasteless, inflammable gas, it burns with a bright yellowish flame, and when mixed with oxygen and common air it becomes explosive. A given volume of this gas weighs a little more than half the same volume of common air. (Common air 1000, carburetted hydrogen 553 nearly.)

FIG. 11.

Explosion of Carburetted Hydrogen and Oxygen.

Bi-carburetted hydrogen, is composed, by weight, of twelve parts of carbon and two of hydrogen. This is a colorless, tasteless gas, possessing a marked odor, is highly inflammable, burning with a bright and intensely luminous flame. It forms the better part of our illuminating gas. Like carburetted hydrogen, it is explosive when mixed with common air. Its specific gravity is a little less than that of air (common air 1000, bi-carburetted hydrogen 985). These compounds will receive attention as we enter upon an explanation of the chemical changes which take place during the process of combustion.

Recapitulation.

Oxygen is an invisible gas, possessing a powerful affinity for certain elements found in all combustible substances. Heat is required to bring this affinity into rapid action. The higher the temperature, the more intense will be the action, and, consequently, the greater will be the quantity of heat evolved in a given time.

Hydrogen is an invisible gas, an element in most varieties of fuel, combining rapidly with oxygen only at a high temperature, evolving an intense heat and producing water in the form of an invisible vapor.

Nitrogen is also an invisible gas, possessing only negative properties. It combines directly with no other substance, and hence cannot be regarded as a heat-giving element in combustion.

Carbon is a solid, the chief constituent in all kinds of fuel, and, when at high temperature, surpasses all other elements in its affinity for oxygen.

Phosphorus and *Sulphur* are highly inflammable solids, entering into chemical union with oxygen at a lower temperature than most other combustibles.

Carburetted and *bi-carburetted* hydrogen are invisible and highly inflammable gases, burning with a yellow flame. They are formed during the combustion of most kinds of fuel.

PETROLEUM WELLS.

CHAPTER VI.

Analysis of Combustion.

Notions of the Ancients respecting Combustion. —The ancient philosophers held an opinion that Nature consisted of four elements, Earth, Air, Water and Fire. They account for the ascending current of flame, by supposing fire to be the purest and most perfect of the elements, forever tending upward to the *empyrean*, its own home of pure fire and light. This doctrine was taught and generally accepted until the middle of the 17th century, when a new theory was proposed by Beecher, a distinguished German physician and chemist. This theory was known as the Phlogistic Theory. It assumed that there existed in nature a rare, etherial substance called phlogiston. This could not be isolated, but was always present, and formed a constituent part of all combustible bodies. When a substance was burned, phlogiston escaped, and flame was its natural state, but soon it passed into combination with the atmosphere. Thus, for example, when a piece of carbon burns away with a white light, and the product of its combustion is carbonic acid gas, the Phlogistians would say that carbon consists of two elements, carbonic acid and phlogiston ; when the carbon burns its phlogiston is set free as flame or fire, and the dephlogisticated carbonic acid left behind.

This theory respecting the phenomena of combustion, held undisputed sway and was entirely satisfactory so long

as philosophers ignored an experimental study of nature, and remained content in "swinging round the circles" of their own fanciful imaginations. But when Genius retired from the ideal world, and with the true spirit of inquiry commenced to interrogate the living universe of God, the first response pronounced this doctrine unsound, and the retorts and the balance of Lavoisier gave it the death blow.

He demonstrated that, when a body was burned, no such substance as phlogiston was given off, but, on the other hand, that it took to itself a substance which increased its weight. He burned phosphorus in a jar of oxygen, and found that the gas disappeared, and that the phosphorus increased in weight in exact ratio to the loss of the oxygen. Now if this combustible is composed of the material substances, phlogiston and phosphoric acid, and if, when the body is burned, the phlogiston escapes, how does it appear that the phosphoric acid weighed more than the phosphoric acid and phlogiston taken together.

The advocates of this elastic theory were able to cover this ground by assuming that phlogiston *was considerably lighter than nothing*, or to use a less absurd expression, they assumed that phlogiston possessed the property of levity, so that it buoyed up, and consequently greatly diminished, the weight of every body with which it was combined. But the beam of Lavoisier's balance was destined to give the Phlogistians further trouble. He took a flask, and placed in it a given weight of metallic mercury, then filled the flask with pure oxygen and sealed it air-tight. He now accurately weighed the whole. The flask was then heated to 600°, (a temperature at which mercury enters into combination with oxygen, and forms oxide of mercury, or calx,[1] as the Phlogistians would call it.) Lavoisier now weighed the flask, and found that it had neither gained nor lost in weight.

[1] The ancients believed that the metals were composed of calxes and phlogiston, because their oxides resembled chalk. When a metal burned or was oxidized by exposure to the air, the phlogiston had been set free, and the calx remained.

Now, since mercury was a compound of phlogiston and calx, whenever calx was produced from mercury, phlogiston must escape, but since the flask had been hermetically sealed, and also proved by the balance to have neither lost nor gained anything in weight, it follows that, if calx was found in the retort, phlogiston must be found there also. But, on opening the flask, no phlogiston escaped, but the air was heard to rush in, proving that a partial vacuum had been formed in the interior, and calx was found at the bottom of the flask.

The mercury, therefore, on being heated, had not given off phlogiston or anything else to the oxygen of the flask, but had really abstracted a portion of the oxygen from it. Lavoisier demonstrated this in another way. He took this calx or oxide of mercury, and heated it in a suitable apparatus to 900°, and found that he had decomposed the calx into oxygen gas and metallic mercury. The oxygen and mercury being carefully collected, the weight was found to be exactly that of the calx or oxide of mercury employed.

These experiments, therefore, furnish unmistakable proof that metallic mercury is not a compound of its own calx and phlogiston, but that it is an elementary body: and the calx or oxide of mercury is not an element but a compound of metallic mercury and oxygen. Lavoisier also showed that the results of combustion in atmospheric air are the same as those in oxygen gas, only that the air consists in part of pure oxygen, which occasions combustion, and in part of another gas which is a neutral element, and takes no part in the process. It would be natural to suppose that these truths, so clearly demonstrated by the experiments of Lavoisier, would have been readily accepted; but for nearly twelve years he stood almost alone and encountered the opposition of the whole scientific world, and it was not until near the close of the eigtheenth century that his doctrines were generally received.[1] When it had become fully

[1] The stern opposition which Lavoisier was obliged to encounter furnishes a striking exhibition of the obstinate pertinacity with which even the most learned

established, "Madam Lavoisier, robed as a priestess, committed to the flames on an altar, while a solemn requiem was chanted, the phlogistic system of chemistry."

It ill becomes us to ridicule the doctrine of phlogiston while thousands among us entertain notions respecting combustion quite as absurd. Notwithstanding the boasted enlightenment of the present age, and our 60,000 free schools, purporting to educate all classes of the community, it is truly astonishing how deficient is the information of all classes, even those who claim to be educated, respecting so familiar a subject as combustion. Ask what becomes of the vast quantities of wood and coal which are daily thrown into our stoves and furnaces, and in nine cases out of ten the reply will be, "*burned or consumed, burned to smoke and ashes.*"

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and far-seeing are prone to adhere to antiquated doctrines and established opinions. Priestly and Cavendish were the most renowned chemists in England of that day. The former was the discoverer of oxygen gas, a discovery which has furnished man with the key whereby he has been able to unlock the mysteries of nature, and one which has revolutionized the civilized world; for it has given us a knowledge of the composition of the atmosphere, of water, and of the solid crust of the globe, and of their connection with animal and vegetable life, and the great changes which are constantly going on in nature.

The latter of these distinguished men discovered the composition of water, and yet neither of them ever abandoned the exploded doctrine of phlogiston. Cavendish, when it became evident that the new doctrine respecting combustion was about to gain the ascendency, gave up the science of Chemistry in disgust and emigrated to this country, where he afterward died, defending until the last his favorite doctrine of phlogiston.

But no opposition could overthrow the system of truth which Lavoisier had discovered. It is the foundation upon which modern chemistry is built. His labors in other departments of science were of great value to his country and the world. He took a prominent part in originating and perfecting the French system of weights and measures, which will, sooner or later, be recognized as the true standard throughout the civilized world. We might suppose that this celebrated man would have received that respect, admiration and homage due him by his countrymen and the world,—but not so: during the "Reign of Terrer" in France he was arrested and condemned to die. He asked for a respite for a short time in order that he might complete some researches, the result of which, he claimed, would be beneficial to mankind. The judge replied that "France wanted no scientific men," and on the following day he was dragged to the guillotine.

And when scientific men attempt, by the aid of chemistry, to present an enlightened view of the subject, to point out errors, and suggest the application of well established principles, they exclaim, "Away with your fine-spun theories, and hair-splitting experiments. Give us something real, something tangible, something practical;" just as if there is nothing real or practical respecting the combustion of fuel except smoke and ashes. *Positive fuel, comparative smoke, superlative ashes*, the *Alpha* and *Omega* of combustion. Nor can it be expected that the masses, or even those intelligent men connected with manufactories, managers of railroads, or directors of steam navigation will possess a very large fund of reliable information concerning the combustion of fuel, while rejecting the aid of science they become the obedient pupils of a class of cackling patent mongers, who are deficient alike in knowledge and integrity.

The writer of these pages met, a short time since, a man who claimed to have discovered a method of burning, not only all the smoke, but all the gases formed in the process of combustion. On being asked what gases he burned he replied, "All." "Do you burn the nitrogen and the carbonic acid?" "Certainly," was his prompt reply. "What do you mean by *burned?*" "Consumed." "What do you mean by *consumed?*" "Burned up—destroyed forever." This Socrates of the nineteenth century was instructing the benighted citizens of Boston that all former theories respecting combustion had heen exploded, etc. His invention consisted of a small piece of wire gauze placed at the entrance of the escape pipe.

With such teachers it is not a matter of surprise that we hear people talking about burning smoke, burning the air, "burning the gases of the air," burning the oxygen of the air, etc. Let it be remembered by all, that smoke will not burn, nor will air burn, nor will oxygen burn, nor will hydrogen burn, nor will carburetted hydrogen burn, nor will bi-carburetted hydrogen, nor will carbonic oxide burn, nor will carbon burn *unless brought into contact with other elements.*

There is not "a combustible" substance either simple or compound, known in the universe, that is, there is no substance known which possesses the inherent property of burning when taken alone. It is only when a body is acted upon by some other body that the phenomena of fire are possible. "Combustibility is not a quality of the combustible taken alone; it is merely a faculty which may be brought into action through the instrumentality of a corresponding faculty in some other body." To illustrate this take six jars—let the first be filled with atmospheric air, the second with oxygen, the third with hydrogen, the fourth with carburetted hydrogen, the fifth with bi-carburetted hydrogen, and the sixth with carbonic acid,—open the mouth of the jar filled with the common air and introduce a lighted taper or match, the match continues to burn but the air does not take fire, if it did the whole interior of the jar would be filled with flame, nor would the air burn if it were intensely heated.

Now introduce a lighted taper into a jar of oxygen. The taper burns with intense brilliancy, but the oxygen does not take fire. Try the jar filled with hydrogen, exercising caution in introducing the lighted taper that we do not allow the air to mingle with the hydrogen, the taper is immediately extinguished, nor does the hydrogen itself take fire. And if we should try the same experiment with either the carburetted hydrogen, the bi-carburetted hydrogen, or carbonic oxide, in each case the taper would be extinguished and the gas refuse to take fire.

Meaning of the term Combustion.—*Combustion* is the process in which two or more elements enter into chemical union, attended by the liberation of heat and light, and the production of a new compound or compounds.

Combustion, in the more popular or general acceptation of the term, is restricted to that form of rapid chemical action which occurs between the oxygen of the air and the carbon and hydrogen of certain organic substances, as wood, coal, and other varieties of fuel. The terms *burning* and *consuming* are common expressions for the same process.

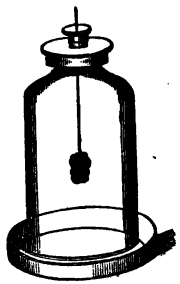
Generally, excepting in cases of combustion, chemical action is brought about for the sake of obtaining some valuable products resulting from this action. Thus we effect the chemical union of sulphur and mercury to obtain the bright red paint called vermilion. But in combustion, the *products* are regarded as worthless. In burning charcoal we cause carbon and oxygen to unite, not for the sake of the carbonic acid which is produced, but on account of the heat which is only an *incidental result* of such a union. So in the case of illumination we bring about chemical action, not for the products formed, not for the heat, but for the *light*, which is another *incidental* result of chemical action.

Combustion will take place only when two or more substances, which have an affinity for each other, are brought in close contact, and in the case of fuel a high temperature is indispensible. Any three of these conditions may be complied with, and still no combustion occur.

Experiment.—Take an iron retort, fill it with charcoal, exclude the air, and allow no other substance to come in contact with it. It may be heated in a furnace for days or weeks, but no combustion will take place. The carbon will remain unchanged, unless there is some other substance present to act upon, or unite, with it. *Therefore, two substances, at least, are necessary* to produce combustion.

Experiment.—Take a jar of oxygen and lower into it a piece of rock crystal (quartz), the rock does not burn. Heat both the rock and oxygen, and no change is effected. Here are two substances; they are brought into contact so that the atoms which compose the exterior of the quartz must come in contact with the atoms of oxygen which fill the jar, the temperature is sufficiently high. Why then does not the quartz burst into flame? Simply because there is no affinity between the two substances. The quartz is composed of silicon and oxygen; at some previous time the silicon has taken its

FIG. 12.



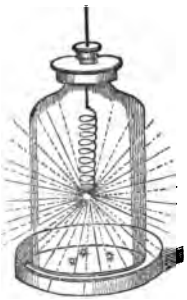
Quartz in Oxygen.

equivalents of oxygen, and it will take no more, hence it may be regarded as a product of some previous combustion.

Therefore, to render combustion possible, *the two substances must have an affinity for each other.*

Experiment.—Take the jar containing the oxygen and burning wire (Fig. 13). The wire did not ignite till it was actually brought in contact with the oxygen. We might have lowered it to within a sixteenth of an inch of the upper stratum of oxygen and no combustion would have taken place. *Combustion, therefore, requires that the substances shall be brought in close contact with each other.*

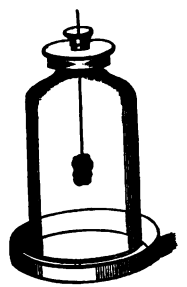
FIG. 13.



Iron Burning in Oxygen.

Experiment.—Take another jar of oxygen. Plunge into it a piece of carbon without heating it. No combustion occurs. Why not? Because the chemical attraction of these substances is so graduated that they do not come into active play at a low temperature. Combustion, therefore, *requires that one or both of the substances be at a high temperature.* Hence, combustion is possible only under the following conditions :—

FIG. 14.



Cold Carbon does not Burn in Oxygen.

1st. There must be at least two substances.

2d. The substances must have a chemical attraction for each other.

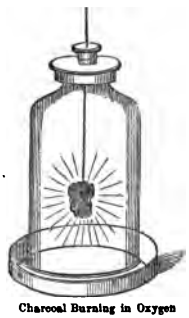
3d. The substances must be in close contact so that their atoms shall be within the range of chemical action.

4th. In cases of ordinary combustion a high temperature is required.

Experiment.—Now take a case where all these conditions are complied with. Lower into a jar of pure oxygen, (Fig. 15), a small piece of charcoal heated to incandescence; as it enters it brightens and glows with a pure white and

brilliant light. It grows smaller and smaller, and after a time entirely disappears. What has become of this solid mass? We say it has been consumed—burned up. What do we mean by this? Not that the atoms, of which the carbon was composed have been destroyed or annihilated, for amid all the countless changes of nature not an atom of matter is destroyed or lost. If we examine the contents of the jar we shall find that its weight has increased by just the number of grains that the charcoal weighed: this shows us that the carbon is still within the jar, but in another form. If the contents be submitted to a chemical analysis we shall find it contains carbonic acid, which is composed of two elements, carbon and oxygen, 6 grains of the former to 16 of the latter.

FIG. 15.

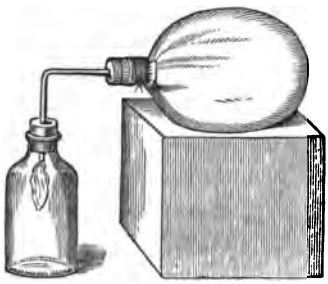


Charcoal Burning in Oxygen

It has been stated that carbon, when at a high temperature, has a strong affinity for other elements. When, therefore, this bit of charcoal was heated and introduced into the jar, the atoms which composed the exterior of the charcoal came in close proximity to the atoms of oxygen with which the jar was filled; these atoms were urged towards each other by the force of chemical affinity and when they clashed, this force was suddenly arrested and given out in the form of heat, just as when we strike a piece of iron with a hammer, the force of the blow is suddenly arrested, and that force is given out as heat. So intense was the heat developed by the clashing between the atoms of carbon and oxygen that the piece of charcoal was kept at a white heat, and the compound formed by the union of its atoms escaped as carbonic acid; this prepared the way for other atoms to clash, and so the process continued until either the carbon or the oxygen or both were consumed. When we say a substance is consumed or burned we mean that the substance has entered into combination with an other substance and through this combination heat has been evolved.

Experiment.—If we force a small stream of hydrogen (Fig. 16) into a jar of oxygen, and apply a lighted match to the jet, a pale flame and intense heat is produced. How shall we explain these phenomena? In precisely the same way as we did in the former case (Fig 15). At a high temperature the atoms of hydrogen and oxygen have a strong affinity for each other; they come in contact at the point where the small stream issues from the tube; they clash, and by means of the collision great heat is evolved, and a pale light is given out.

FIG. 16.



Hydrogen Burning in a Jar of Oxygen.

Upon examining the jar after the operation, water is found in the interior which, if collected and weighed, will equal the sum of the weights of the hydrogen and oxygen before entering into chemical union. If this experiment should be conducted in a jar filled with atmospheric air, the result would be the same, only the action would be less violent, and a large volume of nitrogen would be found in the jar after the substances were formed.

What Occurs in the Burning of Oil or Gas.—Take the case of ordinary flame produced by the burning of gas or oil. The chief constituents of these substances are carbon and hydrogen in a state of chemical union, called hydrocarbon. From this colorless gas escapes the soot or lamp black which we see ascending from our lamps and gas-burners when the combustion is imperfect.

When we turn the stop-cock of a common gas-burner, the coal gas (hydro-carbon) rushes out; the surface of the compound gas is brought into contact with the oxygen of the air, and, by applying heat from a burning match, chemical attraction is instantaneously called into action and so intensified that the gas bursts into a brilliant flame. At this high temperature the oxygen has an attraction for both the hydrogen and carbon. It first seizes upon the hydrogen,

evolves heat and produces water, while the carbon is set free. A countless number of atoms of carbon are now floating in the midst of the burning mass. These become white hot, and to them, while in this state of intense incandescence, is the light chiefly due. But the carbon at this high temperature has a strong attraction for the atoms of oxygen which are constantly rushing towards the flame, induced thither by the current of ascending vapors; the atoms of oxygen unite with the atoms of floating carbon; heat is developed and an invisible gas, composed of six parts of carbon, and sixteen of oxygen, is produced; this is carbonic acid—the same substance that we had in the jar after burning the charcoal in oxygen. Combustion, therefore, is a chemical change effected *upon*, but not an annihilation *of*, matter, for in each case the weight of the products formed will be found to equal that of the substances which we say are burned plus the amount of the oxygen which enters into combination with these substances. In each case "we have atoms of dissimilar substances which are separated and are powerfully attracted like lifted weights; they rush together, collision arrests motion, and their force is given out as heat. It is the clash or impact of the atoms of oxygen against the atoms of the elements of the burning bodies which give us the light and heat of combustion. By figuring to ourselves the atoms shot across the molecular space with intense force and thus parting with their excess of motion we have an explanation of the source of heat in combustion."

One circumstance renders it difficult formany persons to realize the fact that nothing is destroyed in the burning process. They see that the solid, ponderable matter rapidly wastes away and disappears, and they infer that it must be lost. This is because the products of combustion are *invisible.* But we should bear in mind that matter may exist, notwithstanding it is incapable of revealing itself to us through the sense of sight. Oxygen, for example, as well as the atmosphere from which it is derived, is invisible, yet no one doubts the reality of its existence.

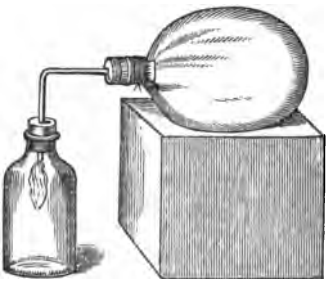
How Combustion Changes Substances. — Burning changes a visible or invisible simple or compound substance and an invisible simple substance into one or more invisible compound substances. This is only another illustration of the law stated on page 54, namely, that all chemical compounds are unlike their constituent elements. The two invisible gases, nitrogen and oxygen, combine to form a visible fluid. The black solid, carbon, and the yellow solid, sulphur, form a colorless liquid. The products of combustion are not, however, *always* invisible; the product obtained from the combustion of hydrogen may be made visible. If we bring the invisible vapor in contact with some cold substance, it will be condensed into a liquid which possesses every property of pure water. Sometimes combustion affords a solid residue. Thus, when phosphorus is burned in oxygen, a white powder, resembling snow, will settle in the bottom of the jar, which may be seen and weighed as easily as sugar or salt. If two grains of phosphorus are burned, the product, (phosphoric acid,) will weigh four and half grains, and at the same time it will be found that exactly two and a half grains of oxygen have disappeared.

Combustible and Supporter.—Many suppose that hydrogen, carbon and other elements called "*combustible*" possess some inherent quality, which renders them capable of producing flame and heat, or are endowed with the property of burning, while atmospheric air is regarded as "*a supporter of combustion.*" But no one who has given his attention to the foregoing simple experiments can fail to see that such a distinction has no foundation whatever.

Experiment.—It was shown by the experiment page 78, (Fig. 16,) that if a jet of hydrogen be ignited in an atmosphere of oxygen, heat and light would be developed and water produced. If now we fill the bag with oxygen and the jar with hydrogen, and ignite the small stream of oxygen, (Fig. 17) as it enters the jar of hydrogen, precisely the same phenomena will be witnessed, and result produced, as in the preceding experiment. In this case, the oxygen is

"*the combustible*," and the hydrogen "*the supporter*." With what propriety, then, can we say that the hydrogen is "*a combustible* and the oxygen is not, or that the oxygen is "*a supporter*" of combustion and the hydrogen is not? The hydrogen does not burn any more than the oxygen, nor does the oxygen support the combustion any more than the hydrogen. The action is mutual. Both are equally active in the process, and are related to each other in every way alike; therefore the terms "combustible" and "supporters of combustion" are not strictly correct. In the combustion of coal, wood, etc., we obtain the oxygen from the air which is brought in contact with the fuel; when the air is cut off, the combustion ceases. We say that the air, or more properly the oxygen of the air supports the flame, and hence comes the name "*supporter of combustion*" While, with this explanation, we continue to use these names, let it be understood that they are only conventional terms, which might, without any impropriety be made to exchange places.

FIG. 17.



Oxygen Burning in a Jar of Hydrogen.

What takes place when we kindle a fire. — We have a cold stove, cold fuel, cold air, and a cold match. We draw the match across a rough surface, the friction raises the temperature above 150°, at which point rapid chemical action takes place between the phosphorous of the match and the oxygen of the air, it bursts into a brilliant flame, developing heat sufficient to induce chemical affinity between the sulphur of the match and the oxygen of the air, they unite, a flame is produced, and sufficient heat evolved to ignite the hydro-carbon which has been set free from the wood through the agency of the heat produced by the combustion of the phosphorous and sulphur. The oxygen now seizes first upon the hydrogen of the hydro-carbon, heat is sent out and water produced. The atoms of carbon have

now become heated to a white heat. They now unite with the atoms of oxygen, evolving heat, and form carbonic acid. We now apply this burning match to the fuel, which must be a substance that contains volatile hydro-carbons, as the heat from the match would not be sufficient to ignite carbon. It must also be in a state of fine division, because large surfaces would conduct away the heat of the burning match, so that no point would be sufficiently heated to become ignited, but if the pieces are small, some sharp edge or point will readily take fire; the heat from these is communicated to other portions of the fuel, and, if there be a due supply of air, the whole mass will in a short time commence to burn. To make a fire, then, we first ignite the match by friction. The phosphorus combines with the oxygen; heat is evolved through this combination, and phosphoric acid is produced; the sulphur unites with the oxygen, heat is evolved and sulphurous acid produced; carburetted hydrogen is driven off from the wood of the match; the hydrogen combines with the oxygen, heat is evolved, and water is produced; the carbon from the wood of the match unites with oxygen, heat is evolved and carbonic acid is produced; carburetted hydrogen is formed from the fuel; the hydrogen combines with oxygen, heat is developed, and water is produced The carbonaceous portion of the hydro-carbon unites with the oxygen, heat is evolved, and carbonic acid is produced. When all the volatile hydro-carbons have been consumed, no flame will be seen, but the carbon is in a state of incandescence and continues to burn until the whole is consumed.

Quantity of Heat.—The quantity of heat evolved depends upon the number of atoms of oxygen *brought into action;* therefore, that substance which enters into combination with the largest volume of oxygen will evolve the most heat. Thus, every ounce of hydrogen in burning combines with 8 ounces of oxygen, while an ounce of carbon will absorb only $2\frac{2}{3}$ ounces of oxygen; consequently, the heating power of hydrogen is to carbon as 3 is to 1. The calorific power actually obtained by experiment does not quite agree

with the foregoing statement, but the apparent discrepancy may arise from the difficulty of rendering available all the heat developed by chemical combination.

Analytical Table, exhibiting the Calorific Power of some of the Elements and Compounds which enter into Chemical Union with Oxygen, all of which are employed in the Combustion of Fuel.

Names of the Elements and Compounds.	No. of parts of Water heated 1° F. by the combustion of 1 part of the substances.
Hydrogen in combining with Oxygen to form water,	64832
Carbon in combining with Oxygen to form Carbonic acid,	14432
Carbon in " " " " " Carbonic oxide,	4530
Carbonic oxide in combining with Oxygen to form Carbonic Acid,	9902
Bi-carburetted Hydrogen in combining with Oxygen to form Water and Carbonic Acid,	21632
Carburetted Hydrogen in combining with Oxygen to form Water and Carbonic Acid,	27032

Remark.—The quantity of water raised one degree by the combustion of a given quantity of these substances, indicates only an approximation to their real heat-producing powers, as it is somewhat difficult, in performing the experiment, to exclude all disturbing influences. The results obtained are always under the true value, in consequence of the losses which are sustained. By glancing at the table it will be seen that the heat evolved by combustion of hydrogen is more than four times that of an equal weight of carbon. These results nearly agree with those obtained by the researches of Fave, Silbermann and Rumford. Others assign a greater heating power to carbon, even as high as 21603 because they claim that nearly one-fourth of the heat evolved is rendered latent on effecting the gasification of the carbon. If this last view of the case be correct the total

calorific power of carbon is to that of hydrogen as the quantities of oxygen with which they respectively enter into combination, as stated on page 82.

Temperature required for Ignition.—A very interesting peculiarity of ordinary combustion is the fact that its beginning requires a high temperature. We consider coal, wood, oil, sulphur, and gunpowder very combustible, but there is no combustion, although oxygen is present, until they are set on fire or ignited, that is, until some portion is heated to a high temperature. Oxygen is very different from other "supporters of combustion" in this respect, for with them combustion begins at ordinary temperatures. If chlorine were suddenly put in the air in place of oxygen, or if the oxygen should assume its active form known as ozone, everything combustible upon the earth would take fire and be consumed with fervent heat in a few hours. This property of oxygen, to which we allude, is another of the striking evidences of the adorable Wisdom everywhere to be found in the order of nature. The temperature of ignition varies greatly for the different combustibles. Phosphorus, sulphur, and sodium take fire below a red heat, while the ignition point with others is so high that we rarely have an opportunity to see them burn. The combustible nature of iron, lead, copper, silver, and gold, was not even suspected until a recent period. We know now that they burn more readily and fiercely than any common fire, when they are once kindled; if we wanted to make the most gorgeous pyrotechnic display possible, it could be done by making a bonfire of a few tons of iron in an atmosphere of oxygen. The ignition temperatures have been determined for only a few substances. Phosphorous ignites at 150°; sulphur at 480°; hydrogen begins to burn at 300°; carbon requires 800° or 1000°; carburetted hydrogen 1000°.

Recapitulation.

Combustion is a form of chemical union which is attended by the disengagement of heat and light.

In cases of ordinary combustion the action takes place between the oxygen of the air and the elements of certain organic bodies, as wood, coal, etc.

Combustion requires that there should be at least two substances.

The substances must have an affinity for each other.

They must be in close proximity to each other.

One or both must be at a high temperature.

When hydrogen enters into chemical union with oxygen, water is produced.

When carbon combines with the largest measure of oxygen, carbonic acid is produced.

When the compounds of carbon and hydrogen burn, the hydrogen and oxygen first unite to form water, then the carbon and oxygen to form carbonic acid.

The weight of the products of combustion is always equal to the weight of the combustibles, plus the weight of the oxygen which is absorbed.

The quantity of heat evolved is in proportion to the quantity of oxygen which enters into chemical union.

Perfect combustion occurs when every atom of the combustible enters iuto chemical union with its equivalent of oxygen.

The products of perfect combustion are water in the form of an invisible vapor, and carbonic acid.

The products of *imperfect* combustion are: water, carbonic acid, smoke, carbonic oxide and other combustible gases.

All the products of perfect combustion of fuel are invisible.

All the products of imperfect combustion are invisible, with the exception of true smoke, that is, of minute particles of pure carbon.

PART II.

THE APPLICATION OF CHEMICAL PRINCIPLES TO THE CONSTRUCTION OF FURNACES.

CHAPTER I.

The Separation of the Volatile and Fixed Constituents of Fuel previous to Combustion.

Preliminary Remarks.—Having alluded, in the former part of this treatise, to the important part which fuel is destined to play in promoting personal comfort and securing national prosperity, and having pointed out some of the more general properties, both physical and chemical, belonging to the different varieties of fuel, and having explained those laws which will prove to be the only correct guide in our efforts to secure the greatest economy in its use, we propose, in the second part of our work, to make a practical application of these facts and principles to the construction and operation of furnaces.

Scientific Principles our Guide in the Construction of Furnaces.—The mechanical engineer will ask, "What have these to do with furnace making or furnace working? Your experiments and laws are well enough for the laboratory and class-room; your theories are plausible enough, but we do not care for these. They have nothing to do with the practical working of a furnace. There is

just so much heat in a pound of coal, and you can obtain no more. If air be admitted to the furnace, nature will do the rest."

It would be well for the objector to bear in mind that the teachings of science and the principles which it enunciates are by no means "theoretical." They are founded upon an analysis and comparison of facts, which have been established by the most careful and pains-taking experiments. It is a principle of Natural Philosophy that two bodies cannot occupy the same space at the same time, but if any man is so unwise as to suppose that this is only a *theoretical* truth, and persists in the attempt to make his head and a brick wall occupy the same space at the same time, he will, after a few well-directed and persevering efforts, become convinced that this principle is a *practical* truth, and one which applies to *his* particular case.

The varied mechanical and chemical mutations effected upon matter are governed by laws fixed, clearly defined and universal in their application. God does not institute certain laws for the nicer experiments of the laboratory, and then make miraculous exceptions to them for the everyday manipulations of common life. If, then, implicit obedience to nature's laws are indispensable to satisfactory results in the one case, it is equally so in the other. Therefore, a knowledge of the nature and properties of the different kinds of fuel, the character of the elements composing the atmosphere, and of the laws of chemical combination have everything to do in determining the construction and arrangement of the different parts of the furnace. A knowledge of these involves the whole question of right and wrong, of entire success or partial failure, of economy and waste.

Our object will be to divest the subject of theoretical difficulty, and present to the reader a series of important practical applications of principles founded upon the basis of experiment.

The Reason why so many Inventions prove Unsuccessful.—There has been sufficient time, money and

skill expended in originating methods and perfecting apparatus for economizing the use of fuel, but unfortunately our inventive genius has been groping its way in the dark, consequently much of it has been on the wrong track. Many of the contrivances which of late years have incumbered the patent list have been based upon no principle, justified by no proof, while some even are in direct opposition to the laws of nature. The reason for this is obvious. Our inventors have been men whom early training and correct habits of thought have not fitted, and whom business has not permitted, to investigate chemical agencies and processes, and they have therefore failed to become masters of the fundamental principles upon which the success of their inventions depend.

What the first step should be.—No practical chemist would attempt to decide on the size, shape and strength of his retort, crucible or other apparatus, without previous consideration of the nature, conditions and tendencies of the substances with which he is about to operate. Now, combustion is a chemical experiment, and as such, is one of the most brilliant, interesting and instructive, within the department of chemical science. *The furnace is the retort.* How, then, can we know how to construct the furnace before we have learned the nature of the process which is to take place? Let us, then, commence at the beginning, and inquire into the nature of the process to which our materials are to be submitted, and understand their respective wants and conditions during that process. Then, and not till then, shall we be qualified to determine the form, dimensions, and peculiar structure of the apparatus best adapted to the operation.

Nature of the Process.—We are to bring about chemical action between oxygen and the several elements of compound bodies, derived from the different varieties of fuel. The oxygen is obtained from the atmosphere. Our object is to obtain the maximum amount of available heat from a given quantity of fuel. This requires perfect com-

bustion. Perfect combustion can only be obtained when *every* atom of combustible matter finds its equivalent of oxygen and enters into chemical union with it. The furnace should be constructed with reference to the conditions required for securing the result. The elements which are to combine with oxygen, are carbon and hydrogen, or compounds of these. As bituminous coal presents a greater number of impediments to perfect combustion than any other variety of fuel, we have selected it for examination and shall attempt to point out the conditions required for its complete consumption.

It is not necessary to enter into detail respecting the various compounds which are formed in different proportions during the combustion of coal, or their effects upon the process. It is sufficient for our purpose to know that all these compounds, excepting those formed of carbon and hydrogen are injurious to combustion. The two most important characteristics of coal, are the carbonaceous or solid and the bituminous or gaseous portions. One of our most distinguished chemists uses the following language: "Carbon and hydrogen unite in several proportions, and form many curious and important compounds, among which it is difficult to distinguish those which ought to be considered as distinct and definite combinations, from others which are probably indefinite measures of the former. These compounds are generally termed hydro-carbons, and amongst them are some striking illustrations of one species of isomerism, that is, of compounds often differing essentially in their physical or chemical properties, or both, and yet apparently produced by the union of the same elements and bearing the same relations to each other."

How Bituminous Coal Burns.—In the natural state of bituminous coal, the bitumen and carbon are united and solid. If we take a piece of charcoal and immerse it in boiling pitch or rosin, until its pores are filled with these substances, we should have a material resembling bituminous coal. On entering into combination the rosin would

be separated from the charcoal before the former could be converted into flame or the latter ignited, nor would the charcoal burn until the resinous matter had been consumed. The wick of a lamp does not burn while there is a supply of oil. Alcohol may be burned upon a piece of paper, but the paper will not be consumed nor acted upon in the least while there is a supply of alcohol, but after the alcohol has disappeared the paper will take fire. This is the case with bituminous coal. It is not a homogeneous mass which is to enter into combustion, and the conditions and wants of each part are essentially different. This is a primary distinction which demands especial attention, for to the neglect of this may be attributed many of the erroneous practices, into which so many have fallen in the construction and management of furnaces.

Important Facts.—In entering upon an investigation of this subject the reader should keep distinctly in view the following facts:—1st. Bituminous coal consists of carbon and bitumen. Bitumen is composed essentially of carbon and hydrogen. 2nd. Coal cannot be ignited while in a state of solid coal, that is, while these two parts are united. The bituminous portion, like oil or tallow, will burn only as it is converted into the *gaseous* state. The carbonaceous portion is combustible only in the *solid state.* The former burns with flame, the latter without.

Destructive Distillation.—Hence combustion in the furnace consists of two distinct processes:

1st. The destructive distillation of the fuel.

2d. The chemical union of the different products of the distillation with the oxygen of the air.

When wood is heated in a close vessel, or with only a limited supply of air, the organic structure of the wood is destroyed and a large number of volatile compounds are driven off. This process is termed *destructive distillation* of the wood.

The number and character of these compounds depend upon the nature of the wood and degree of heat to which

it is subjected. At a red heat, hydro-carbons and pure hydrogen are obtained, while a residue of carbon always remains in the retort, which, in dry wood, amounts to 25 per cent. of the weight.

Experiment.—Put some wood into a test tube, to the mouth of which is fitted a cock with a tube passing through it; heat the test tube to a red heat. The volatile portions of the wood will be set free, pass through the tube, and, on being kindled, will burn with a yellow, luminous flame. On examining the test tube after the gaseous matter has been expelled, charcoal will be found. If the experiment be repeated with bituminous coal, a luminous flame will be produced, and coke will be found in the test tube. If this coal be submitted to heat in larger vessels called coal retorts, the volatile or combustible substances pass off, leaving a solid, carbonaceous matter called coke. These volatile substances consist chiefly of light carburetted hydrogen, heavy carburetted hydrogen gas, a small proportion of carbonic oxide and other substances, some of which are incombustible. This is destructive distillation *without atmospheric contact.* When air is present, as is the case in a furnace, the separation of the gaseous and carbonaceous parts takes place in the same manner, and these volatile hydro-carbons will be consumed, or pass off unconsumed, according to the way in which the oxygen is supplied. The character of these two parts, and their manner of entering into combustion, are essentially different. The general impression is, that coal enters into combustion *at once* on the application of heat, and during the process it evolves the gaseous matter which it contains. This view, however, is not correct, and fails to comprehend a very important feature in the consumption of fuel, viz: the order in which the solid and gaseous portions enter into combination with

FIG. 18.

Separation of the Volatile from the Fixed Portion.

oxygen. When fresh coal is thrown upon a fire the general temperature *is lowered* and *not raised*, as would be the case if this additional mass of fuel was brought immediately into activity. A large portion of heat is first absorbed in producing the expansion and volatilization of the coal, and it has been ascertained that the absorption of heat will be in an exact ratio to the quantity of gases generated. This process of generating the gases termed volatilization, is one of the most cooling[1] in all nature, because a large quantity of heat is converted directly from the *sensible* into the *latent* state. (*Vide page* 4.)

Change Previous to Combustion.—The bitumen of coal, on account of the large proportion of hydrogen which it contains, absorbs heat very rapidly, and the coal is changed into a viscous semi-fluid or pitchy state, and by a greater increase of heat to the gaseous state. Now all this large quantity of heat which is absorbed becomes *latent* in the the gas, and is wholly unavailable until the gas enters into chemical union with oxygen and is consumed. After the volatile portion of the coal has escaped, the coke which remains is expanded and occupies more space than the coal itself. If we watch carefully this process of gasification, we shall observe that so long as any of the volatile portions remain to be evolved, the solid portion remains until the former has been consumed or removed.

This whole process is well illustrated in our gas-making establishments, where are exhibited the relative proportions of these two distinct parts of at least one variety of fuel, viz: bituminous coal; and where is also shown what an enor

[1]There is great danger of underrating the quantity of heat absorbed and rendered latent by the expansion and volatilization of the bitumen of coal. Evaporation and gasification are the most effective means of producing an extremely low temperature. A little ether placed upon the hand evaporates rapidly, and absorbs so much heat that a sensation of cold is felt. Carbonic acid gas becomes a liquid under a certain pressure; if the pressure be removed, it returns to the form of a gas with such rapidity that if mercury be brought in contact with it, it is frozen, and may be hammered like a piece of lead. In this way water may be frozen in a red hot crucible.

mous quantity of heat is required to effect this change, as two-thirds of the entire solid portion, or coke, is used in producing the separation of these hydro-carbons.

Just the same expenditure of heat must take place when we effect a separation and expel the volatile portion from coal in our furnace. There is, however, the difference in the the *retort*,—no loss of heat is sustained, because the gas, on being liberated, is collected and retained in the gasometer for subsequent use, but no arrangement has been made for retaining it in the furnace, consequently much heat is lost. Thus, after the volatile portion of the coal has absorbed so much heat as to reduce the temperature of the interior of the fire chamber below the point of ignition, the volatile or gaseous portion which is set free, whether in a retort or furnace, is always associated with several other substances, tending more or less to diminish its heat and light-giving properties. In gas-making establishments these impurities are removed by a process called purification, but in the furnace this purification cannot be obtained, and hence the entire gaseous products of the coal, good and bad, are indiscriminately mixed and consumed, or carried away as they are generated.

This important feature seems to have been overlooked in the construction of furnaces. It has been a current opinion that anthracite coal, which contains a much smaller proportion of this volatile matter, possesses greater heating properties than other varieties, yet numerous experiments show that more heat can be evolved from the combustion of a given number of pounds of bituminous coal than from the same number of anthracite coal, provided we can overcome the physical and chemical impediments to perfect combustion which exist in the bituminous, but do not exist in the anthracite.

In some localities where bituminous coal only can be obtained, the coke alone is used for locomotive purposes. On account of the practical difficulties in rendering the heating powers of the volatile portions available, the coal is placed

in ovens and the entire gaseous portion is expelled, at the expense of an enormous waste of fuel, to say nothing of the cost of the operation itself.

Recapitulation.

Bituminous coal consists of two distinct parts,—the bitumen or volatile portion—the carbonaceous or solid portion.

The former will enter into union with oxygen only in the aeriform state. The latter only in the solid state.

Neither are capable of being ignited while combined.

A fresh charge of coal, on being thrown into a furnace, absorbs a large amount of heat which has been derived from the combustion of some previous charge.

This heat expands the bitumen, and changes it from a solid to a viscous semi-fluid, resembling pitch or tar.

By further absorption of heat, this viscous mass is expanded into an enormous volume of gas, consisting mainly of carburetted hydrogen.

As ice will absorb a large amount of heat until converted into water, and water continue to take up heat until entirely converted into vapor, so the bitumen in coal will continue to absorb heat until changed from a solid to a semi-fluid, and from a semi-fluid to a gaseous state.

The carbonaceous portion remains unconsumed until the volatile part has been expelled. The order of these several distinct processes is as follows:—

1st. The expansion and fusion of the bitumin.

2d. The generation of an immense volume of gas.

3d. The absorption of a large quantity of heat during these changes.

4th. The combustion of the gaseous portion.

5th. The combustion of the carbonaceous portion.

CHAPTER II.

Character of the Volatile Constituents of Coal, and the Quantity of Air Required for their Complete Combustion.

Proportion of Each Constituent.—The volatile products evolved from coal by heat, are hydrogen, carburetted hydrogen, bi-carburetted hydrogen, carbonic oxide, a small percentage of nitrogen, ammonia and other substances. The exact proportions of each of these depend upon the variety of coal, and also upon the intensity of the heat applied. Frequently the proportion of carburetted hydrogen is as great as 83 per cent. of the whole; and, at a very high degree of heat, and during the later stages of the process, the proportion of hydrogen is increased, in some instances, to 20 per cent., though the percentage is, generally, much less, while the amount of bi-carburetted hydrogen seldom exceeds 10 per cent.

We see, then, that the main bulk of coal gas is carburetted hydrogen; for the only difference between carburetted and bi-carburetted hydrogen is in the proportion of hydrogen which they contain, as carburetted hydrogen is composed of two equivalents of hydrogen and one of carbon, and bi-carburetted hydrogen of two equivalents of hydrogen and two of carbon, while there is generally a sufficient amount of pure hydrogen produced, to convert the bi-carburetted into carburetted hydrogen if united with it, and it makes no difference for purposes of combustion whether this hydrogen

be in a state of chemical union or not, as the two elements are separated in burning. We are, therefore, warranted in the conclusion that the principle part of the volatile portion of coal, amounting to 80 or 90 per cent. (excluding impurities) is carburetted hydrogen.

Quantity of Gas Obtained from a Ton Of Coal. —From information gathered at our gas-making establishments, we find that no less than 10,000 cubic feet of gas are obtained from a ton of bituminous coal. We must bear in mind that this gas is the same whether generated in the retort of the gas-house, or in the furnace, excepting that the impurities are removed, previous to combustion in the former case, and not in the latter.

When we remember that this 10,000 feet of gas, if brought in contact with air through a well-adjusted argand or other burner, is capable of producing an immense heating and illuminating effect, and that the coke, which remains after the volatile matter has been expelled, will burn without smoke and produce an intense heat, and when we see these two valuable constituents, united in the form of coal, thrown into a furnace, and so imperfectly burned that the smoke, escaping from the chimney, becomes a positive nuisance, so that, in many cases, the whole of the 10,000 feet of gas are expelled, and only the remaining coke is made use of, we can but conclude that there is something *radically wrong* in the construction of our furnaces.

That this is the case, will become evident as we proceed with our investigations, and our object will be to show how the volatile portion of coal may be burned as completely in the fire-chamber of a steam boiler, as in the jet from a gas pipe.

What is it that is required, to consume and render available for purposes of heat, this huge volume of gaseous matter? Simply to meet those conditions which are required to cause every atom of carbon and hydrogen contained in it, to find and enter into chemical union with their respective equivalents of oxygen.

These conditions may be briefly stated as follows:

1st. That there must be a due supply of oxygen, as determined by the laws of chemical combination.

2d. That there must be admitted a sufficient quantity of atmospheric air to supply this oxygen.

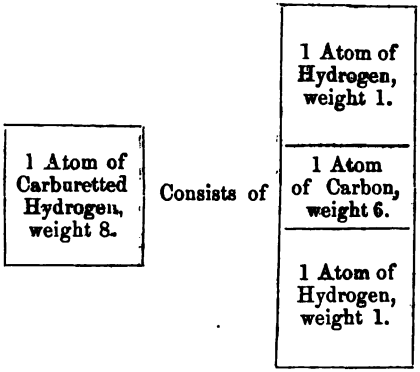
3d. That this air must be pure; it must not be deteriorated by being deprived of a portion of its oxygen, nor contaminated by the products of some previous combustion.

4th. That this air must be admitted at the *time*, at the *place*, and in the *manner*, which will bring the atoms of hydrogen and oxygen, and of carbon and oxygen within the sphere of chemical attraction.

5th. That due regard must be had for the temperature required to produce chemical action between the hydrogen and oxygen, and the carbon and oxygen.

The Quantity of Air Required.—The first step, towards affecting the complete combustion of coal gas, is to ascertain the quantity of oxygen, with which its elements will enter into chemical union. This question cannot be decided by the dictum of any chemist, or by the ingenious contrivances of any mechanical engineer; for "it was foreordained and predestinated from the foundation of the world" that these elements should enter into chemical union, only in fixed and definite proportions. (*Vide page* 54, *paragraph* 8th.) This branch of our subject is not, then, made up of "a complicated tissue of uncertainties," but, independent of all speculation, is reduced to a matter of unerring calculation. As it has been stated on page 67, carburetted hydrogen is a compound gas, consisting of two equivalents of hydrogen and one of carbon, or two atoms of hydrogen for every one atom of carbon. The weight of an atom of hydrogen is one, that of carbon, six, but the volume, or bulk, of an atom of hydrogen is double that of an atom of carbon, and these, when in a state of chemical union, are condensed into two-fifths their previous bulk, or into the bulk of a single atom of hydrogen.

Fig. 19.


1 Atom of Carburetted Hydrogen, weight 8.
Consists of
1 Atom of Hydrogen, weight 1.
1 Atom of Carbon, weight 6.
1 Atom of Hydrogen, weight 1.

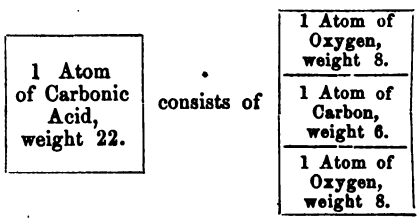
Let Fig. 19, represent an atom of carburetted hydrogen with its constituents of hydrogen and carbon; the space enclosed by the lines, representing the comparative volume of each, and the numbers, their respective weights. Now it has been shown that this compound gas, on entering into combination, becomes decomposed, and that its constituent elements unite with oxygen by separate processes. It is, therefore, important that we examine their respective weights, volumes and other properties.

1st. The volume of Oxygen required for the Combustion of the Hydrogen of a given volume of Carburetted Hydrogen.—One atom, or equivalent, of hydrogen requires one atom or equivalent of oxygen, but there are two atoms of hydrogen in every atom of carburetted hydrogen, therefore, for the combustion of the *hydrogen* of every atom of carburetted hydrogen, two atoms of oxygen are required. But, since the *bulk* of an atom of hydrogen is just double that of an atom of oxygen, for the combustion of the hydrogen of a given volume of carburetted hydrogen, it requires a *volume* of *oxygen*, equal to exactly *one half* that of the *hydrogen*. If, for example, we have one cubic foot of carburetted hydrogen, we shall obtain, after decomposition, *two* cubic feet of hydrogen, the combustion of which will require *one* cubic foot of oxygen, and the oxygen and hydro-

gen, after chemical union, will be condensed into two cubic feet of steam.

2nd. The Volume of Oxygen Required for the Combustion of the Carbon of a Given Volume of Carburetted Hydrogen.—One atom of carburetted hydrogen contains one atom of carbon. (*Vide Diagram* 2.) When we burned carbon in the jar of oxygen, carbonic acid was produced. This consists of two atoms of oxygen for every atom of carbon, and these three atoms are condensed, after chemical union, into two-thirds their original bulk, as illustrated by Fig. 20.

FIG. 20.



Then, for the combustion of the atom of carbon contained in an atom of carburetted hydrogen, it requires two atoms of oxygen, or a volume of oxygen double that of the carbon.

Since the bulk of an atom of oxygen is only one half that of hydrogen, the volume of these two atoms is exactly equal to that of one atom of hydrogen, or one half the volume of hydrogen in an atom of carburetted hydrogen; it, therefore, requires the same volume of oxygen, for the carbon as for the hydrogen of the carburetted hydrogen, hence for both, double the volume; or for every foot of coal gas, two feet of oxygen. Therefore, for the complete combustion of the 10,000 feet of this gas, obtained from a ton of coal, twenty thousand feet of oxygen must be provided. The number of atoms employed in the combustion of one atom of coal gas, and their relative volumes and weights may be shown in a condensed form, thus:—

FIRST CONSTITUENT OF CARBURETTED HYDROGEN.

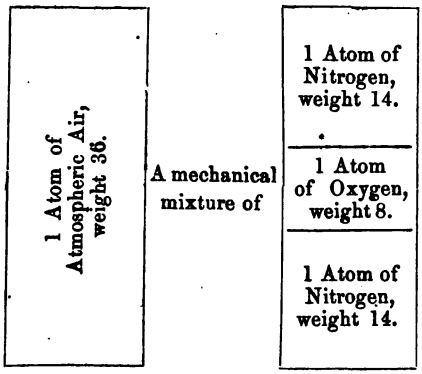
Hydrogen.		Oxygen.				
Vol.	*Atom. Weight.*	*Vol.*	*Atom. Weight.*		*Vol.*	*Atom. Weight.*
2	2	2 unite with 1	2	16 forming steam	2	2 18

SECOND CONSTITUENT OF CARBURETTED HYDROGEN.

Carbon.		Oxygen.				
Vol.	*Atom. Weight.*	*Vol.*	*Atom. Weight.*		*Vol.*	*Atom. Weight.*
½	1 6	unite with 1	2	16 forming carbonic acid.	1	1 22

The Quantity of Air Required to Supply the Necessary Volume of Oxygen.—Atmospheric air is composed of one atom of oxygen, for every two atoms of nitrogen, but the bulk of an atom of nitrogen is double that of oxygen (*vide page* 56), therefore the *volume* of the nitrogen in air, is four times that of the oxygen, as shown in Fig 21.

FIG. 21.


1 Atom of Atmospheric Air, weight 36.
A mechanical mixture of
1 Atom of Nitrogen, weight 14.
1 Atom of Oxygen, weight 8.
1 Atom of Nitrogen, weight 14.

Hence, to obtain one cubic foot of oxygen, for purposes of combustion, we are obliged to make use of five cubic feet of atmospheric air.[1] Then, to obtain the twenty thousand cubic feet of oxygen, necessary for the complete combustion of the gaseous portions of a ton of coal, requires five

[1]The elements which compose the atmosphere have the same volume when taken separately, as when united, whereas the elements of steam, carburetted hydrogen, carbonic acid and many other compounds, *are condensed* on entering into chemical union, but we must bear in mind that these are *chemical compounds*, while the atmosphere is only a *mechanical mixture* of its elements.

times twenty thousand, or *one hundred thousand feet of air.* It must not be supposed that ten thousand cubic feet is the *exact* amount of gas given off, from one ton of coal, during combustion; besides, this contains a per centage of bi-carburetted hydrogen and carbonic oxide, which somewhat varies the amount of air required, yet this is sufficiently accurate for the purpose of illustration. It has, then, been shown beyond doubt or contradiction:—

1st. That every volume of carburetted hydrogen requires, for its complete combustion, *two* volumes of oxygen.

2d. That it requires *five* volumes of air to furnish *one* volume of oxygen; hence *ten* volumes of air for the combustion of one volume of carburetted hydrogen.

3d. Not less than ten volumes of air will satisfy the conditions of perfect combustion.

4th. If an excess of air be admitted, it passes through the furnace uncombined, absorbing and carrying with it a quantity of heat.

5th. If *less* be provided, it is evident that a portion of the carburetted hydrogen must pass off unconsumed.

Bi-carburetted Hydrogen.—So small is the percentage of bi-carburetted hydrogen, that we have thought it unnecessary to make a special investigation concerning its combustion. However, it may be well to notice the distinction between it and carburetted hydrogen.

This, as we have seen, is composed of *one* atom of carbon for every *two* of hydrogen, while bi-carburetted hydrogen contains *two* atoms of carbon for every *two* of hydrogen, and it is obvious that this additional atom of carbon will require two additional atoms, or one volume of oxygen. Hence, if one volume of carburetted hydrogen requires, for its combustion, *two* volumes of oxygen or *ten* volumes of air, one volume of *bi-carburetted* hydrogen requires three volumes of oxygen, or *fifteen* volumes of air.

Explanation of Diagram.—Diagram 2 will help the reader to comprehend the several changes which occur during the complicated process of combustion. It will also

enable him to grasp and fix both the relations, as to quantities, between the several bodies which enter into chemical union, and the compounds which such quantities relatively produce during this process.

In Fig. 1, on the left, are represented the constituent elements of a single atom of carburetted hydrogen.[1] In the same column, just below, are represented four atoms of air, which is the exact amount required for the perfect combustion of the atom of carburetted hydrogen, thus :—

1 atom of carburetted hydrogen, —a chemical compound of { 1 atom of Carbon, 2 atoms of Hydrogen, } Both combustible.

1 atom of atmospheric air, —a mechanical mixture of { 1 atom of oxygen, a supporter of combustion. 2 atoms of Nitrogen, neither combustible nor a supporter of combustion.

Four atoms of atmospheric air, contain four atoms of oxygen and eight of nitrogen ; there is, then, an aggregate of fifteen elementary atoms, employed in the combustion of a single atom of carburetted hydrogen.

In the *second column*, Fig. 2, may be seen the elements composing the atom of carburetted hydrogen in a state of chemical union, condensed to two-thirds their original bulk.

Directly below are represented the constituents of *air* in their combined state, but, since this is only a mechanical mixture, there is no diminution of bulk. It has been shown (p. 53) that chemical union can take place only between substances, which are removed at insensible distances from each other. Therefore, these atoms must be brought into contact previous to combustion.

Fig. 3 represents the atoms of the compound gas and air, brought within the limit of chemical attraction. On the application of the required degree of heat, chemical action begins, and a complete change takes place. The car-

[1]It must be remembered that the colored circles show the relative *volume* or *bulk* of the respective atoms, while their relative *weights* are indicated by the numerals placed just below the name of each, at the bottom of the page. The relative volumes of carbon and hydrogen in any one atom of carburetted hydrogen show their relative volumes in any larger quantity, as each atom of the compound gas has exactly the same chemical composition.

Diag

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Fig. 1.
Constituent Elements of Carburetted Hydrogen and Atmospheric Air.

Fig. 2.
Single Atoms of Air and Carburetted Hydrogen being compounds of the Constituents as in the preceding column.

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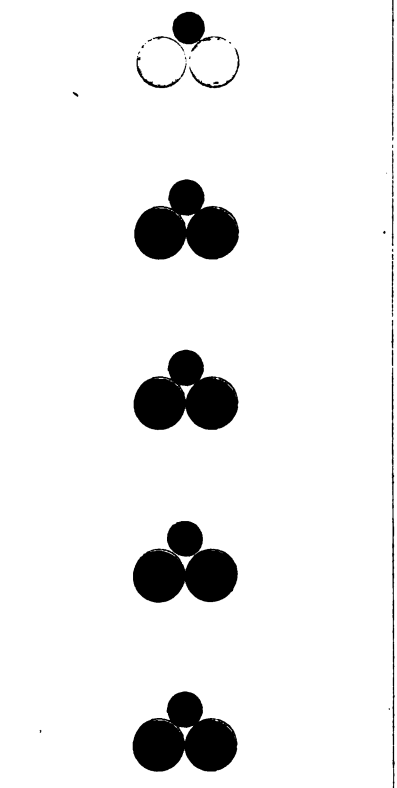
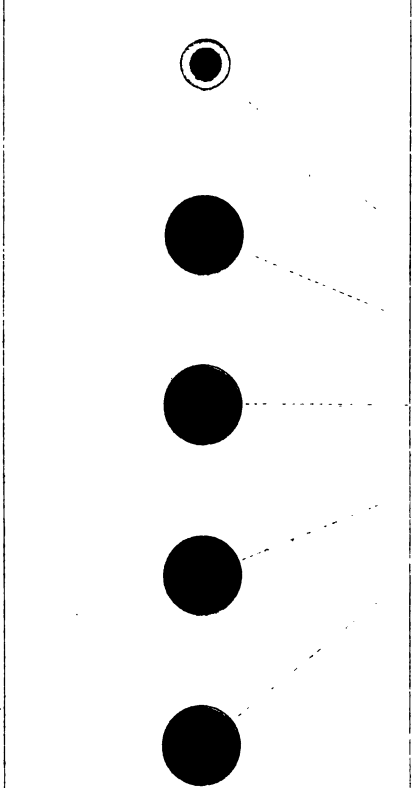
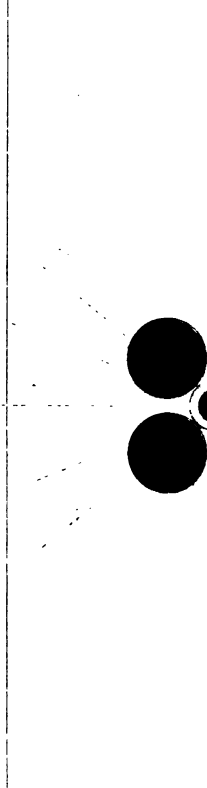
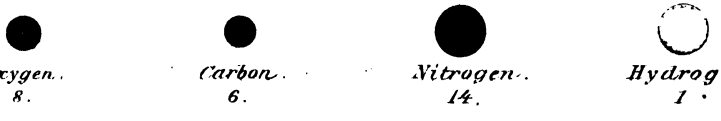






Fig

Explanation of the Symbols in the above Diagram



Oxygen. 8.
Carbon. 6.
Nitrogen. 14.
Hydrogen. 1.

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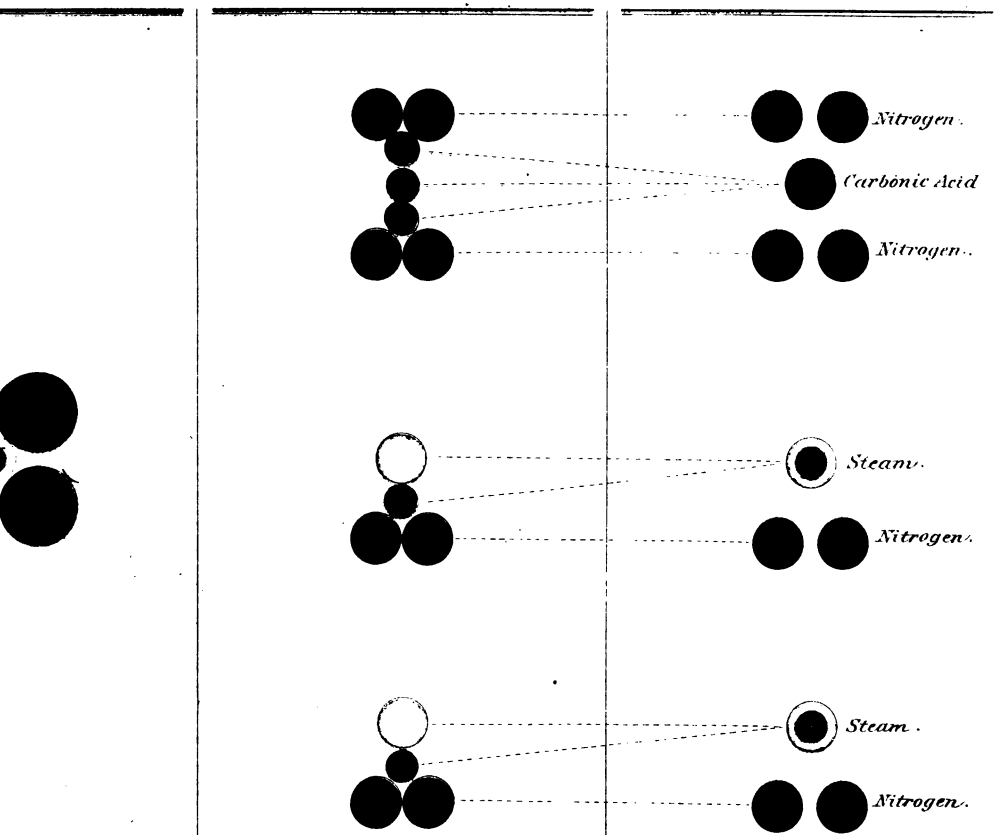
Fig. 4.

State of Decomposition of Carburetted Hydrogen preparatory to the Chemical Union of their Constituents with their respective Equivalents of Oxygen

Fig. 5.

Products of the Combustion of one Atom of Carburetted Hydrogen with its equivalent of Atmospheric Air.



6.

with their relative Weights and Volumes.

Carburetted Hydrogen. 8.

Carbonic Acid. 22.

Steam. 9.

Atmospheric Air. 36.

bon and hydrogen are now in a state of chemical union. The one atom of carbon, and the two of hydrogen, are held together by the force of chemical attraction. When heat is applied, the attraction between the hydrogen and oxygen becomes greater than between the hydrogen and carbon, therefore, the elements are separated, and the atoms of hydrogen and oxygen rush together. The carbon is now set free at a high temperature, and unites with the two remaining atoms of oxygen to produce carbonic acid.

Fig. 4 represents the first stage of the process, on the breaking up of the compound gas, when each of the elements attaches to itself its own equivalent of oxygen. The nitrogen, on account of "its neutrality," has taken no part in the process, and is left unattached, and we see that the atom of carbon, and each of the two atoms of hydrogen, are supplied with the exact proportion of oxygen required for their chemical union.

Fig. 5 shows the products of these unions.

1st. One atom of carbonic acid, formed by the union of the atom of carbon with its equivalent of oxygen, and condensed into two-thirds the space occupied by its elements.

2d. The two atoms of steam, each formed by the union of one atom of hydrogen and one of oxygen, and condensed into two-thirds the volume of its elements.

The first impression, on inspecting the diagram, is the large volume of air, required for the combustion of so small a volume of coal gas. But, when we take into consideration the preponderating quantity of nitrogen, which is present, the reason for this becomes obvious. This, however, is unavoidable so long as we depend upon atmospheric air for our supply of oxygen. If it be true, (and no scientific truth is more firmly established) that elements will combine only in the proportions here represented, we can readily comprehend the loss resulting from a deficiency of either.

Recapitulation.

The main bulk of the volatile constituents of coal is carburetted hydrogen.

Nearly ten thousand feet are produced from every ton of bituminous coal.

This coal gas possesses great heating and illuminating properties.

The coke burns without smoke, and evolves an intense heat.

The perfect combustion of the two constituents of coal requires:—

1st. A supply of *pure* air sufficient to furnish the adequate volume of oxygen.

2d. This air must be admitted at the *time*, at the *place*, and in the *manner*, which will bring the atoms of hydrogen and oxygen, and of carbon and oxygen, within the sphere of chemical attraction.

3d. Due regard must be had for the temperature required to induce chemical action between "*the combustible*" and "*the supporter.*"

For the complete combustion of the *volatile* constituents of a ton *of coal*, 100,000 feet of pure atmospheric air is required.

Too limited a supply of air occasions a loss of combustible gases, or their hydrogen enters into chemical union with oxygen, and the carbon escape as smoke.

An excess of air robs the fire chamber of heat, and prevents complete combustion, by reducing the temperature below the point at which rapid chemical action is possible.

CHAPTER III.

Character of the Coke, and Volume of Air Required for its Combustion.

The Coke.—Having shown the quantity of air required for the combustion of the volatile portion of the fuel, we will now consider the subject with reference to the solid carbon which remains after the gaseous portion has been consumed, or, as is too often the case, *carried away unconsumed.* The solid part which remains does not differ essentially from the coke which comes from the retorts of gas-making establishments. This is chiefly carbon, yet not pure carbon, as there is always a certain percentage of earthy matter left, after combustion. Carbon is the only heat-giving element contained in the mass. Carbon unites with oxygen in different proportions, giving rise to three distinct compounds. These are carbonic acid, carbonic oxide, and oxalic acid. Only the first and second are formed during the combustion of coal. We have already referred to the first. It is composed of two equivalents of oxygen, and one of carbon. It is a colorless, odorless gas, neither combustible nor a supporter of combustion. It will extinguish the flame of burning bodies, even when mingled with four volumes of air. This property of carbonic acid has rendered it serviceable in extinguishing fires in coal-mines. In one of these mines in England, a fire which had continued for thirty years was extinguished by the use of this gas. The carbonic acid was generated by passing a current of air through a furnace of coal, and blown into the mine until

all its passages were filled with it, and further combustion prevented. The weight of carbonic acid is a little more than one and a half times that of air (air 1, carbonic acid, 1.529).

Quantity of Oxygen Required.—From the unchangeable law of chemical combination, it follows that the production of carbonic acid from the solid carbon will necessarily be the same as in the case of the[1] carbon found in the carburetted hydrogen. Every atom of carbon requires two atoms of oxygen for the formation of carbonic acid. If the weight of an atom of carbon is six, that of each atom of oxygen will be eight. Therefore, for the combustion of six pounds of carbon, sixteen pounds of oxygen will be required.

Assuming that the coke constitutes eighty per cent. of the weight in a ton of coal, we shall have sixteen hundred pounds of coke. As it requires sixteen pounds of oxygen for the combustion of six pounds of carbon, for sixteen hundred pounds of carbon it will require forty-two hundred sixty-six and two-thirds of oxygen. Now, one pound of oxygen at a temperature of 60° contains nearly eleven and one-fourth cubic feet, and forty-two hundred sixty-six and two-thirds pounds will contain forty-eight thousand cubic feet. But, since the oxygen of the air is diluted with four times its bulk of nitrogen, it will require five times forty-eight thousand, or two hundred and forty thousand, cubic feet of atmospheric air for the complete combustion of the sixteen hundred pounds of coke. It has already been shown that it requires one hundred thousand cubic feet of air for the combustion of the gases generated previous to the combustion of the solid mass. Adding this to the two hundred and forty thousand cubic feet required for the coke, we have an aggregate volume of *three hundred and forty thousand* cubic feet of atmospheric air required for the combustion of a

[1] In its elementary state, carbon has never been raised to a vapor. But its constituent particles must have a gaseous arrangement in such of its compounds as are found in the aeriform state, as carbonic acid.

Diagram 3.

Showing how Carbonic Acid is converted into Carbonic Oxide.

Fig. 1.
Constituent Elements of Carbonic Acid and their Volume after Chemical Union.

Fig. 2.
Constituent Elements of Carbonic Oxide and their Volume after Chemical Union.

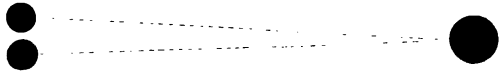


Fig. 3.
Constituent Elements of Carbonic Acid and their Volume after Chemical Union.

Fig. 4.
Two Atoms of Carbonic Oxide which have been formed from One Atom of Carbonic Acid by the addition of one Atom of Carbon

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ton of bituminous coal. This would make a column of air more than sixty miles in length, and a foot square. This estimate is by far too low for practical application. For it will be noticed that this is the *minimum* quantity which will effect complete combustion, independent of any *excess* of air which may enter the furnace. This estimate is also made on the supposition that the temperature of the air is 60°, but on passing between the heated bars of the grate, and among the incandescent coal, it becomes heated and its volume greatly expanded. If a larger proportion of air than complete combustion requires, be forced into the furnace, the excess of air, passing through the fire, hinders combustion by carrying away heat and by cooling the ignited surface of the carbon. It thus attracts the oxygen less strongly, and in consequence the fire languishes or *deadens*, as we say. If the furnace be supplied with *less* than the required volume of air, particles of carbon fly away as soot or smoke. We might suppose this would be the only loss sustained. This would be true if carbonic acid was the only compound formed by the union of carbon and oxygen. There is, however, another and most important state in which carbon combines with oxygen and passes away. This is a compound known as *carbonic oxide*. Carbonic *acid*, as we have seen, is composed of one atom of carbon for every two of oxygen, while, in carbonic *oxide*, one atom of oxygen is combined with every atom of carbon. Diagram 3, Fig. 1. represents an atom of carbonic *acid*, with its constituent elements, two atoms of oxygen and one of carbon, at the left. Fig. 2. represents an atom of carbonic *oxide*, with its constituent elements, one atom of oxygen and one of carbon.

This carbonic *oxide* is a transparent, colorless gas. When inhaled, it is exceedingly injurious to the respiratory organs. Air, which contains only one part in a hundred of this gas, is said to be fatal when inhaled for any considerable length of time. In close, heated rooms, where coal is used for fuel, deaths are often caused by closing the escape-pipe, or leav-

ing the stove door open and allowing the gas to escape into the room. This fatal effect is usually attributed to carbonic acid, but this poisonous gas not unfrequently enters the room mingled with carbonic *oxide*, a gas still more deadly in its effects. The cause of the formation of such a poisonous compound is of interest here. It cannot be the product of *complete* combustion of carbon, for, as has been shown, carbonic *acid* is the only product of that process. The mode by which this gas is sometimes obtained in the laboratory for experiments will give an insight into the manner of its formation in the furnace. If we take an iron or porcelain tube, place in it fragments of charcoal, heat it to redness, and then pass a stream of carbonic acid over the heated coals, the carbonic acid will lose half of its oxygen and be converted into carbonic oxide. The oxygen which has been given off will unite with the heated coal and form another volume of carbonic oxide.

A similar reaction takes place in the furnace. If the supply of oxygen be sufficient, carbonic acid will be formed. If carbonic acid be produced and brought in contact with heated carbon, with no free oxygen, the carbonic acid will lose half its oxygen and become carbonic *oxide*. The liberated oxygen will unite with the heated carbon and furnish an equal volume of the same gas.

Fig. 3 in Diagram 3, shows one atom of carbonic acid, and the volume of its constituents. When an atom of carbonic acid is brought into contact with heated carbon, one of the atoms of oxygen leaves the carbonic acid, and this acid becomes carbonic oxide. At the same time, the atom of disengaged oxygen unites with an atom of carbon and forms another atom of carbonic oxide of the same volume as the first. Hence, in changing carbonic acid to carbonic oxide, we have doubled the volume of gas, and doubled the amount of carbon, while the quantity of oxygen remains the same.

It has been shown that the quantity of heat obtained from any given quantity of fuel will be in proportion to the amount of oxygen with which it can be made to unite.

Since carbon unites with only one half the amount of oxygen in the formation of carbonic oxide that it does in the formation of carbonic acid, it follows that only half as much heat will be evolved in the formation of the former as of the latter.[1] In other words, carbonic oxide is carbon half consumed. It is, therefore, a combustible gas, and, unless some means be devised for effecting its combustion, a very serious loss will be sustained.

How Carbonic Oxide Burns.—The combustion of this gas is just as distinct a process as that of carburetted hydrogen, and it demands all the preparatory conditions, viz: a definite supply of air; mixture previous to combustion; and a high temperature. In stoves where all the air is admitted through the grate, and forced to pass over the burning fuel, carbonic oxide is always generated in greater or less quantities. As it rises to the surface, it usually comes in contact with small quantities of air entering through the cracks around the door or other small openings. The gas here ignites and burns with a flickering, pale blue flame. This phenomenon may almost always be seen in an anthracite or charcoal fire just after fresh coal has been added.

If this gas find a supply of air at the top, it is all consumed—that is, it combines with another volume of oxygen and is converted into carbonic acid. In this case, no loss of heat is sustained. If one half or one fourth the required quantity of air be present, only one half or one fourth is consumed. If the carbonic oxide find no air at the surface, it escapes unconsumed; yet, since it is invisible, the combustion seems to be complete.

Burning Smoke.—The formation of carbonic oxide,

[1]This estimate respecting the loss sustained in the form of carbonic oxide is by far too low. Dulong claims that one part of carbon in becoming carbonic oxide will generate only heat sufficient to raise 2698 parts of water 1°, while one part of carbonic *oxide*, in becoming carbonic acid, will raise 10,569 parts 1°. The reason for this is apparent, as in the former combination, a large portion of heat is absorbed to produce the gasification of the carbon.

from carbon and carbonic acid in the furnace, has led many practical men astray. The stove doctors of the day have filled the country with contrivances for "*the burning of smoke*," for "*the combustion of smoke.*" We claim and shall hereafter attempt to show that this is absurd. We will here mention only one of the numerous errors into which these men have fallen.

When, from an insufficient or redundant supply of air, or from other causes, combustion is incomplete, the carbonaceous constituent of the coal is set free in the form of smoke. This smoke is made to pass over heated bars of iron, or other heated substances, and, as we are gravely told, is *consumed.* Carbonic acid is always mingled with the smoke, and when the two are brought together at a high temperature, as by contact with these heated substances, the *invisible* carbonic acid, and the *visible* smoke unite (in the manner before described) and produce *invisible* carbonic oxide. This, we are asked to believe, is "*burning the smoke;*" but, in truth, the *form* only is changed without saving the smallest fraction of heat.

Why this Carbonic Oxide does not Burn.—It may be asked why the carbonic acid thus produced does not ignite at this high temperature. It does not simply because there is no oxygen to unite with it. If a sufficient supply of oxygen had been present, it would not have been produced. If oxygen be admitted, it takes fire, and heat is evolved. Since carbonic oxide has already taken one equivalent of oxygen, it inflames at a lower temperature than either hydrogen or carburetted hydrogen. It is often sufficiently heated after passing to the mouth of the chimney to ignite on coming in contact with the air. This accounts for the flame which is frequently seen at the top of chimneys, or of the smoke-pipes of steam vessels. This fact should be sufficient to teach us that *heat alone* will not effect the combustion of these combustible products of imperfect combustion. *Oxygen* is required, and we may as well attempt to overturn the laws of gravitation as to burn these substances without it.

Quality of the Air.—When we speak of furnishing a given volume of oxygen for a given amount of coal gas, or of coke, we do so because the laws of chemical combination require just this amount in order that every atom of both gases may enter into union and produce complete combustion. We also speak of a given volume of common air as being sufficient to supply the required quantity of oxygen. We do so, knowing that any volume of *pure* air will contain a definite proportion of oxygen.

When we say that *ten* cubic feet of air are sufficient to effect perfect combustion with *one* cubic foot of coal gas, we state this on the supposition that the ten cubic feet of air contain twenty per cent., or two cubic feet of oxygen. If this atmospheric air has been deprived of part of its oxygen, or mixed with any other simple or compound substance, it no longer sustains the character of pure air, nor does it satisfy the conditions of complete combustion. Hence, if it can be shown that a portion of the oxygen is withdrawn from the air before it comes in contact with a large portion of the coal gas, and the carbon in the fire-chamber, it is evident that complete combustion is impossible. In this case certain quantities of hydrogen and carburetted hydrogen escape uncombined, for the want of a proper supply of oxygen, and consequently a large amount of heat is lost. That the air *is* thus vitiated, or deprived of a part of its oxygen will be shown in another portion of this treatise.

Mr. Parkes, in the "The Transaction of Civil Engineers," observes that he found that smoke increased by the admission of air, the pressure of steam fell in consequence, and failure was unavoidable. On examination, he found that the failure could be traced to the *deterioration* of the air in passing over the inflamed fuel.

"In illustration of this, let us suppose 100 represents the quantity of air required per minute for the perfect combustion of the gaseous products; and that 200 represents the quantity required for the use of the carbon on the grate. Let us further suppose, that instead of sending each of those

quantities *separately* to perform its respective duty, by giving up its constituent oxygen to its proper combustible, (and for which express duty it was employed,) we send the *entire* of quantities, say 300, through such burning mass of solid both carbon; can we doubt that the result would be, first, the impelling this latter to an increased and undue action, and, secondly, the vitiating of the air intended for the gaseous combustibles, by depriving it of its due proportion of oxygen.

For what is this increased action of the carbon on the grate but increased combustion? and what is this but an increased absorption of oxygen, the very oxygen which had been intended for a different purpose. This cannot be denied, neither will it, that the direct result is to deteriorate the *quality* of the 100 measures of air thus sent by an improper route to the gaseous constituent of the coal.

Let us suppose another case, one of laboratory practice; that of ascertaining the largest quantity of carbonic acid and water that could be produced from any given quantity of coal-gas and air, for this is, in fact, what we desire to effect in the furnace.

After adjusting our apparatus and measuring the proportions of gas to be operated on, and the air to be mixed with it, suppose we should discover that the latter, instead of being pure atmospheric air, had been the product of some previous experiment or operation, in which it had been mixed with ignited carbon. What would the veriest tyro of the laboratory say? Would he not reject the whole as unsatisfactory, and begin again, requiring the air to be brought from an unvitiated source!

Yet, this is our daily practice. We bring air to the gases which has already been employed in a separate and even destructive process, and yet expect the result to be satisfactory and the combustion complete. And when we find, instead of producing carbonic acid and water, that we have produced a large volume of *smoke*—of unconsumed combustible matter—we then set about inventing a process by which *this smoke is to be consumed*, and the evil we had ourselves produced corrected."

Recapitulation.

The coke which remains after the volatile portion has been expelled constitutes from 50 to 80 per cent. of bituminous coal.

If coke be brought in contact with a due supply of air, it burns without flame, evolving an intense heat and producing carbonic acid gas.

The complete combustion of the coke produced from a ton of coal requires about two hundred and forty thousand cubic feet of air.

If there be a deficiency in the supply of air, the atoms of carbon will unite with one instead of two equivalents of oxygen, and carbonic *oxide*, instead of carbonic *acid*, will be produced.

Carbonic oxide is an invisible, inflammable gas, lighter than common air. It is carbon half burned. If brought in contact with a due supply of air it burns with a pale blue flame, evolving heat, and producing carbonic acid. If no air be supplied, it readily escapes unconsumed, on account of its levity. This is a source of great waste in the *use* of coke, anthracite coal and charcoal.

Carbonic acid, produced in the lower part of the fire-chamber, is converted into carbonic oxide, and passes up through the red-hot embers.

One volume of carbonic acid produces two volumes of carbonic oxide.

In the conversion of carbonic acid into carbonic oxide, a large amount of heat is absorbed, and unless the carbonic acid find a supply of air, and be consumed, it will occasion a serious loss of heat.

If the air admitted to the furnace has been deteriorated by the loss of a portion of its oxygen, or contaminated by carbonic acid, it cannot effect the perfect combustion of either the gaseous or solid portions of the fuel.

CHAPTER IV.

On the Association of Atoms required for Complete Combustion.

We have seen that the quantity of air admitted to the furnace determines the proportional quantity of fuel which may be rendered available for the production of heat. We are now to consider another still more important question, namely, the degree of mixture which is required between the substances termed combustible, and the supporter of combustion. That this is a subject of greater importance than the quantity will appear from the fact that the *quantity* determines whether *all* the coal gas shall be made available, or only a *part* of it, while the degree of mixture, involves the question whether *any* of the volatile portion of the coal shall enter into chemical union with oxygen, and thus become available as a source of heat.

There seems to be an established opinion among practical men, that if there be a strong draft and an abundant supply of air, nature will complete the process. A closer examination of the subject will show, however, that this operation involves a physical impossibility. It has been shown (page 53) that chemical action will take place only between atoms of different substances, removed from each other at insensible distances. If sal ammoniac and lime require to be ground in a mortar to bring the atoms of each within the sphere of chemical attraction, how can we expect hydrogen and oxygen to unite without such a mixture of their respective atoms.

Dr. Ure, in his Chemical Dictionary, informs us that gun-powder is composed of given weights of nitre, charcoal and sulphur, intimately blended by long pounding in wooden mortars, and that the variations in strength are occasioned by the relative fineness of division, and intimate mixture of the several ingredients. Nitre does not detonate unless it comes in contact with an inflammable substance; hence, the whole operation will be more speedy, the more numerous the surfaces of contact, and this surface contact will, of course, depend upon the intimacy of blending. We shall find that a proper mixture of the respective atoms, as a preparation for the complete union and combustion of the elements employed in the consumption of fuel, is just as important as in the case of the gun-powder.

It is true that, if we fill a gallon jar two-thirds full of hydrogen, and the other third with oxygen, and then apply a burning match, we shall have a violent explosion without waiting long for the intermingling of the atoms of these two gases; but in this case the quantity taken is very small, and, generally, we pass these gases slowly through water so that they have time for mingling. Besides, these gases are free from the effects of currents, from the presence of other gases, and from various other disturbing influences which are met with in the furnace. We can readily perceive the great difference between these two operations, when we consider that in the laboratory only a gallon of gases is to be mingled, while in the furnace there are five cubic feet of gas for every pound of bituminous coal; this five feet of gas must be mingled with fifty feet of air. In some of our large furnaces more than five hundred pounds of coal are consumed per hour, which would require the mingling of twenty-five hundred cubic feet of coal gas with twenty-five thousand feet of air in a single hour, and this is to be accomplished for the combustion of only the volatile portion of the coal, and under many opposing influences. So numerous are these counteracting influences that we may note only a few of the most important.

1st. The bodies to be mingled are partly solid and partly gaseous.

2d. The gases evolved are heterogeneous, being partly combustible, partly incombustible, and partly supporters of combustion.

3d. The air which has passed over the incandescent fuel is mingled with a large quantity of carbonic acid, which has a much greater specific gravity than the other gases.

4th. The air which has passed over the burning mass has necessarily lost a portion of its oxygen, and, consequently, the quantity required to supply the proper amount of oxygen is increased, which will render a perfect incorporation more difficult.

These, and many other circumstances, seriously impede the process of distribution, so that we shall find it utterly impossible to bring about such a degree of incorporation as will enable the atoms of combustible gases to meet their respective proportions of oxygen, and duly arrange themselves for chemical union, before the whole is carried, by the force of the ascending current, beyond the influence of the temperature required for ignition, without which any subsequent mixture would be useless. Some portions of the combustible matter *do* come in contact with the air, and burn, but we have yet to learn how much larger is the quantity, which is carried away uncombined with oxygen, than that which is consumed, and how much the heating effect of what has been consumed has been diminished.

As this branch of our subject is of the utmost importance in a practical point of view, it demands consideration and illustration more in detail.

1st. We will examine the degree of mixture absolutely required for the combustion of the coal gas.

2d. What influences or forces can we depend upon to effect this intimate incorporation?

3d. Are these influences sufficient to overcome all the impediments met in the present arrangement of our furnaces?

We commence by assuming that all chemical action or

Diagram 4.

Representing the Combustion of a given Volume of Hydrogen and its equivalent of Oxygen.

Fig. 1.
Hydrogen to be consumed and its equivalent of Oxygen.

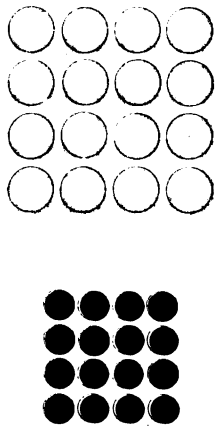


Fig. 2.
Required Mixture of the Atoms in the preceding column preparatory to the Chemical Union

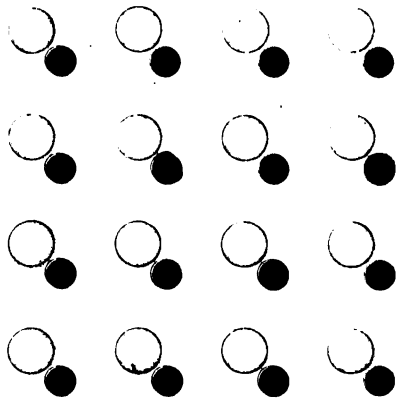
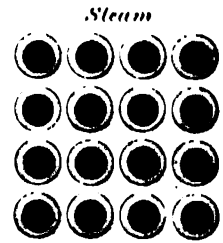


Fig. 3.
Products of the Combustion of a given Volume of Hydrogen and the equivalent of Oxygen



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chemical union requires the atoms of matter to be brought into the closest possible contact, by mechanical mixture, and that the atoms of all gaseous bodies are endowed with the power of moving among themselves with the utmost facility and in all directions.

When we mixed two volumes of hydrogen and one of oxygen, inflated the soap-bubbles with the mixture, and applied heat, chemical union took place simultaneously throughout the entire mass. Had the mixture been fired by an electric spark in a proper piece of apparatus, called an eudiometer, the gases would have totally disappeared, and the interior of the vessel would have been covered with drops of pure water equal in weight to the gases consumed.

Fig. 22.

Now, if chemical affinity is capable of uniting bodies only by atoms, and if these must be in the closest possible relation, what must have been the arrangement of the respective atoms of these masses of hydrogen and oxygen, previous to their ignition by the electric spark?

Explanation of Diagram, Illustrating the Combustion of a Given Volume of Hydrogen.—As one atom of oxygen always unites with one of hydrogen, and as these atoms unite only when in close contact, it follows that the countless atoms composing the mass of the oxygen and hydrogen must have been arranged in sets or pairs as shown in Diagram 4.

Fig. 1 represents a section of a body of hydrogen, and a section of the body of oxygen required for its complete combustion. The different sizes of the circles show the relative volume, or bulk, of any two atoms of these gases. Let us suppose that the red circles representing the oxygen, in Fig 1, be moved towards the yellow circles representing the hydrogen, until the upper row of the red comes in contact with the lower row of the yellow circles. Now, on

applying the degree of heat required to induce chemical action, how many of these atoms would unite? Clearly, only those which were in contact, for chemical affinity acts only on bodies which are at immeasurably small distances from each other; hence, only eight of the thirty-two atoms would enter into combination, and three-fourths of the heat which might have been evolved, would be lost. Before perfect combustion can take place, every one of the atoms of hydrogen must find, and be brought within the attractive influence of its own atom of oxygen.

Fig. 2 represents such an arrangement of the respective atoms, and Fig. 3 represents the product of the several combinations,—sixteen atoms of steam. In this case we notice that not an atom of hydrogen or oxygen escapes uncombined. Consequently, we have the maximum amount of heat which can be developed from the given volume of hydrogen. This gives us a clear idea of the degree of mixture or association of atoms which nature requires for *perfect combustion*, so far as hydrogen and pure oxygen are concerned. It is not claimed that we know, or ever can know, the actual form of an atom of matter, or the precise manner in which the several atoms arrange themselves; but this is certain, that a given bulk of hydrogen will combine with only one-half its bulk of oxygen, and that this union will take place only as they are thoroughly blended. It matters not whether the atoms are required to be in actual contact or not; all that is insisted upon is, that they will unite only when the distances are too small for human vision to detect, just as the finger must be brought within a certain distance from the prime conductor of an electrical machine to induce electrical action.

Experiment.—Spread a small quantity of gunpowder on a plate, so that the grains will be either in actual contact or very near each other, apply a match to any portion and the whole will take fire, because each grain is within the distance required for the transmission of flame; but scatter the powder so that some of the grains shall be beyond the influence of the flame, and these will escape combustion.

Diagram 5.

Representing the Combustion of a given Volume of Carbon and its equivalent of Oxygen.

Fig. 1

Carbon to be consumed and its equivalent of Oxygen.

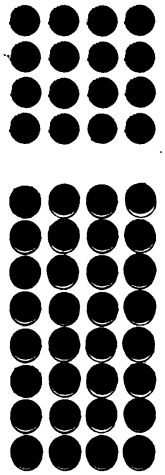

Fig. 2.

Required Mixtures of the Atoms in preceding column preparatory to their Chemical Union

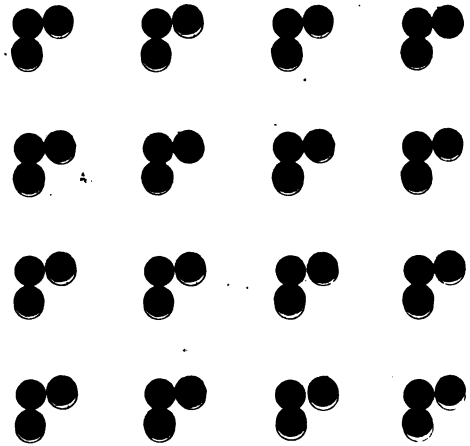

Fig. 3.

Products of the combustion of a given Volume of Carbon and its equivalent of Oxygen.

Carbonic Acid.

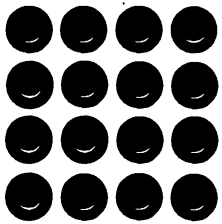

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Diagram 6.

Representing the Combustion of a given Volume of Carburetted Hydrogen and its equivalent of Oxygen.

Fig. 1.

Volume of Carburetted Hydrogen to be consumed and its equivalent of Oxygen

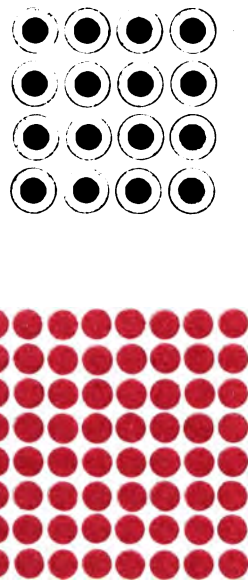
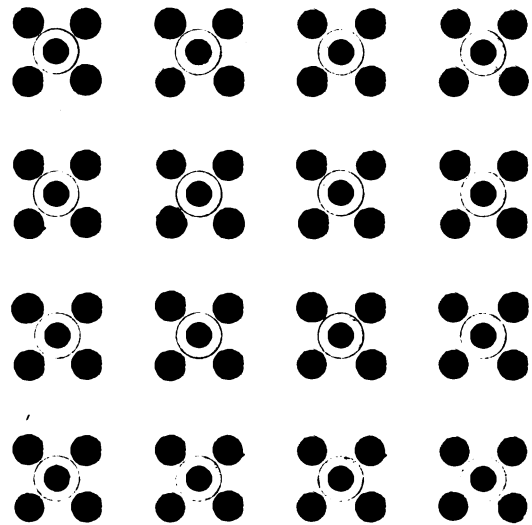


Fig. 2.

Required Mixture of the Atoms in the preceding column preparatory to their Chemical Union.

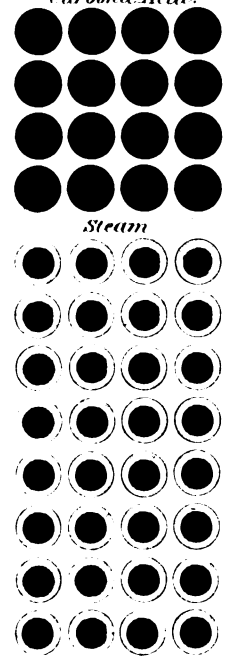


Products of the Combustion of a given Volume of Carburetted Hydrogen and its equivalent of Oxygen

Fig. 3.

Carbonic Acid.

Steam



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So must the atoms of combustible substances and of the supporter of combustion, be within the range of *chemical attraction*, or they will escape combination.

Explanation of Diagram, Illustrating the Combustion of a Given Volume of Carbon.—Having shown the arrangement required for the atoms of one of the constituents of coal gas, let us examine the other, namely: the carbon. For the perfect combustion of carbon, each atom must unite with two atoms, or double its bulk of oxygen. Fig. 1, Diagram 5, represents the carbon and the volume of oxygen required for its combustion. Fig. 2 shows the association of atoms required previous to ignition, and Fig. 3, the resulting product, carbonic acid, being two thirds the original bulk of the mixture. This gives us an idea of the perfect combustion of a given volume of carbon. The proportions between the carbon and oxygen are so definite, and the diffusion of the respective atoms among themselves, so complete, that each atom is within the sphere of chemical attraction before being fired, so that not a single atom of either element escapes combination.

Explanation of Diagram Illustrating the Combustion of a Given Volume of Carburetted Hydrogen.—Let us now examine a case still more complicated in which we have a compound combustible body to be consumed. Diagram 6 represents the required mixture and combustion of a given volume of carburetted hydrogen, with its equivalent of oxygen. Fig. 1 represents the volume of carburetted hydrogen to be consumed, and the volume of oxygen required for its combustion. Fig. 2 shows the arrangement of atoms previous to combination, and Fig. 3, the products of the combustion, carbonic acid and steam. It will be remembered that carburetted hydrogen is composed of two equivalents of hydrogen and one of carbon, and that each equivalent of the hydrogen requires for its combustion one equivalent of oxygen, and that one equivalent of carbon requires two of oxygen; hence one equivalent of carburetted hydrogen requires four equi-

valents of oxygen, and the sixteen equivalents of carburetted hydrogen, sixty-four of oxygen; as shown in the diagram.

It was stated, in the case of the burning candle, that the oxygen seizes first upon the hydrogen. When the atoms are arranged as in Fig. 2, two atoms of the oxygen seize upon the hydrogen of the compound gas, and produce two atoms of steam, as shown in Fig. 3. This sets the carbon free, and soon it unites with the other two atoms of oxygen and produces one atom of carbonic acid. When we can conceive of these changes happening to every one of the countless millions of atoms, of which even a very small quantity of coal gas is composed, we shall have some just conception of what is constantly taking place in the combustion of fuel. These diagrams show us what must take place in order to obtain the most satisfactory results in the combustion of fuel. This degree of incorporation of the elements may seem very difficult, even impossible, in the case of the furnace, yet no fact is plainer than that upon this depends the amount of heat generated, and in proportion as we fail to obtain it, these elements pass away uncombined, which, of course, occasions a great loss.

Explanation of Diagram Illustrating the Combustion of Hydrogen.—But if the perfect mixture seems difficult in the cases just referred to, what shall we say when the oxygen enters the furnace diluted with four times its bulk of the inert element, nitrogen, a substance totally deficient in power to support combustion. The presence of so large a volume of this neutral element will lessen, by four times, the chances for perfect incorporation, and, in addition to this, will absorb and carry away a very large quantity of heat.

If we were obliged to mix thoroughly one bushel of wheat with two bushels of rye, previous to grinding, we should find our task rendered much more difficult if we were obliged to take the wheat with four times its bulk of chaff. Yet it is precisely in this proportion that the oxygen enters

Diagram 7.

Representing the Combustion of a given Volume of Hydrogen and its equivalent of Atmospheric Air.

Fig. 1.

Volume of Hydrogen to be consumed and its equivalent of Atmospheric Air.

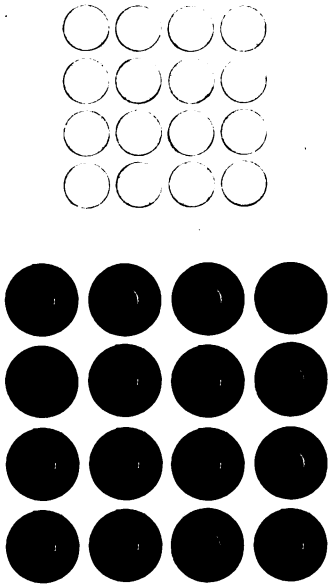
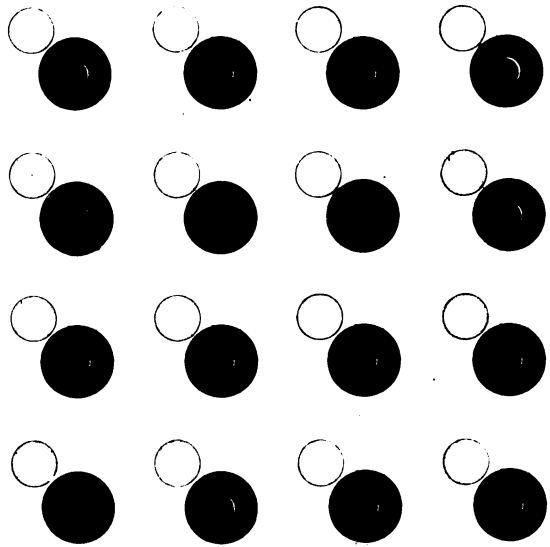


Fig. 2.

Required Mixture of the Atoms in the preceding column preparatory to their Chemical Union.



Products of the Combustion of a given Volume of Hydrogen and its equivalent of Atmospheric Air.

Fig. 3.

Steam.

Nitrogen.

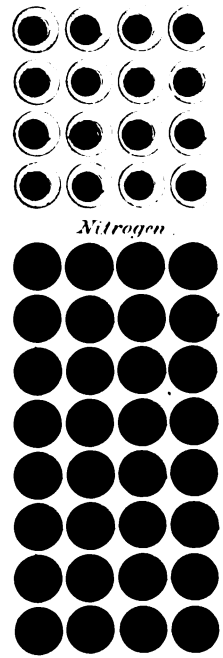


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Diagram 8.

Representing the Combustion of a given Volume of Carbon and its equivalent of Atmospheric Air

Volume of Carbon to be consumed and its equivalent of Atmospheric Air

Fig. 1.

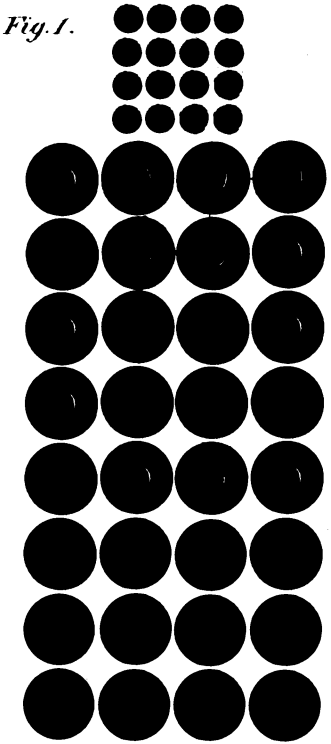


Fig. 2.

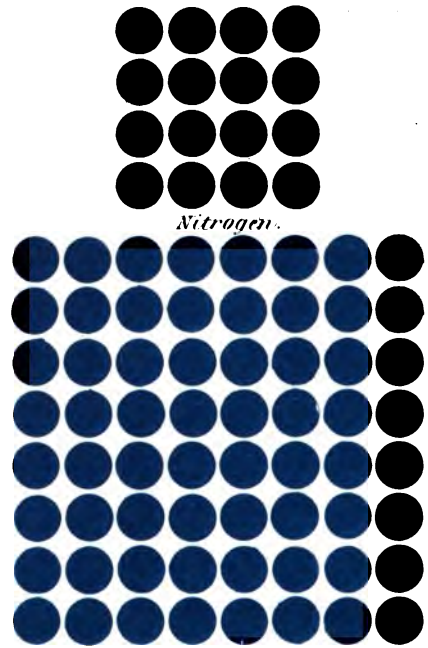
Required Mixture of the Atoms in the preceding column preparatory to their Chemical Union

Products of the Combustion of a given Volume of Carbon and Atmospheric Air

Fig. 3.

Carbonic Acid.

Nitrogen.



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the furnace mingled with nitrogen, which is worse than useless so far as aiding the combustion is concerned.

The next illustration shows the combustion of hydrogen in air. Diagram 7 represents a volume of hydrogen with its equivalent volume of *air*, the mixture required previous to combustion, and the resulting products, steam and free nitrogen. Fig. 1 shows the volume of hydrogen to be consumed, and also the required volume of air. Fig. 2 represents the mixture previous to combustion; and Fig. 3 the volume of steam and of free nitrogen which passes away.

Explanation of Diagram Illustrating the Combustion of Carbon.—Diagram 8 represents the preparatory mixture with air and combustion of a given volume of carbon. Fig. 1 shows the carbon to be consumed, and also the volume of air required for its complete combustion; Fig. 2, the required mixture of the elements; and Fig. 3 the resulting products, carbonic acid and free nitrogen.

Explanation of Diagram Illustrating the Combustion of Carburetted Hydrogen.—Fig. 1, Diagram 9, represents a volume of carburetted hydrogen and its equivalent of air. Fig. 2 shows the arrangement of atoms before combination, and Fig. 3, the products of the combustion, carbonic acid, steam, and free nitrogen. Sixteen atoms of carburetted hydrogen require, for their combustion, sixty-four atoms of air, and give us, after combustion, sixteen atoms of carbonic acid, thirty-two atoms of steam, and a hundred and twenty atoms of free nitrogen.

It is not necessary to give diagrams showing the mixture and combustion of bi-carburetted hydrogen, as the conditions are the same. It will be remembered that the only difference between this and carburetted hydrogen is, that the former contains double the amount of carbon, for the same amount of hydrogen. For the complete combustion of carbonic oxide, one atom (one-half a volume) of oxygen, or five atoms (two and a half volumes) of air are required for

every atom of the gas, and the same degree of mixture as in the foregoing illustrations.

No one can look for a moment at these illustrations without noticing the very large volume of nitrogen which must pass through the furnace, and what an almost insurmountable difficulty the presence of this element offers to that degree of incorporation which perfect combustion requires. On this account, attempts have been made to obtain the oxygen from other sources than the atmosphere, so that the presence of this neutral element may be avoided, and lamps for light-houses and public buildings have been used with success. This method of effecting combustion, however, can never come into general use, until some more simple and less expensive method for obtaining pure oxygen is discovered.

Diffusion of Gases.—Having shown the degree of mechanical mixture necessary for the chemical union of the atoms of coal-gas, and the oxygen of the air, let us now examine the influences, or force upon which we depend to effect this mixture. In Chapter 1, Part 1, it appears that the law which governs the motion of gaseous bodies is different from that which governs the motion of liquids. Oil and water in the same vessel do not unite. The water, by reason of its greater specific gravity, falls to the bottom of the vessel while the oil rises to the top. Every aeriform body, on the contrary, possesses the power of diffusing itself throughout every other aeriform body with which it is brought in contact, in opposition to the force of gravity, until they are so perfectly incorporated that the proportion of any one of the gases, in any fractional part of the mixture, will be the same as the proportion of that gas in the entire mixture, or that all parts of the same volume are composed of the same proportions of the gases employed. Thus, for example, carbonic acid is twenty-two times heavier than hydrogen, yet if the jar E, Fig. 22, be filled with the former, and the jar A, with the latter, when the stop-cocks B and C are opened, after having waited a sufficient length of time,

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Representing the Combustion of a given Volum
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Fig. 1.

Volume of Carburetted Hydrogen
to be consumed and its equivalent
of Atmospheric Air.

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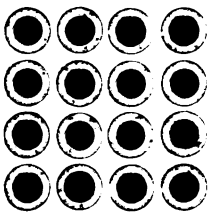

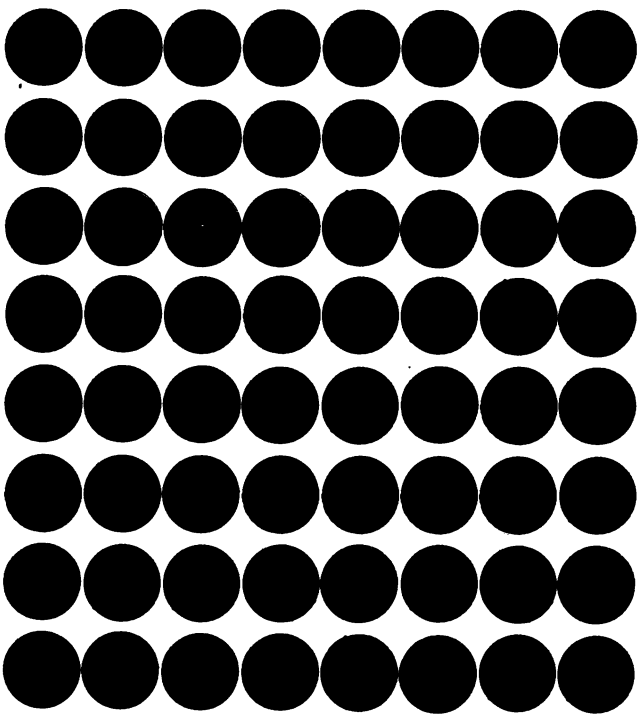

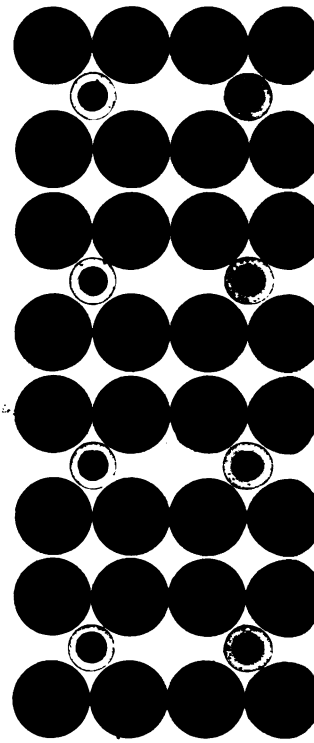

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Carburetted Hydrogen and the equivalent of
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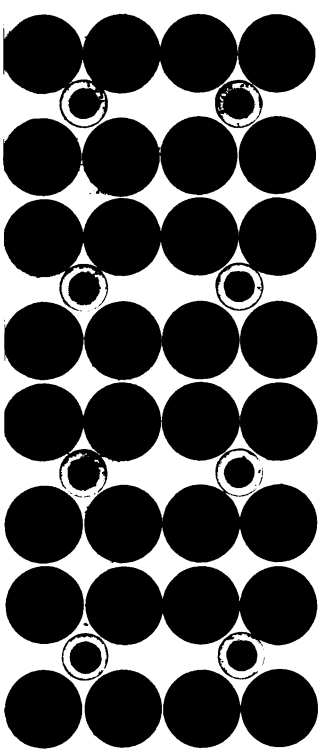
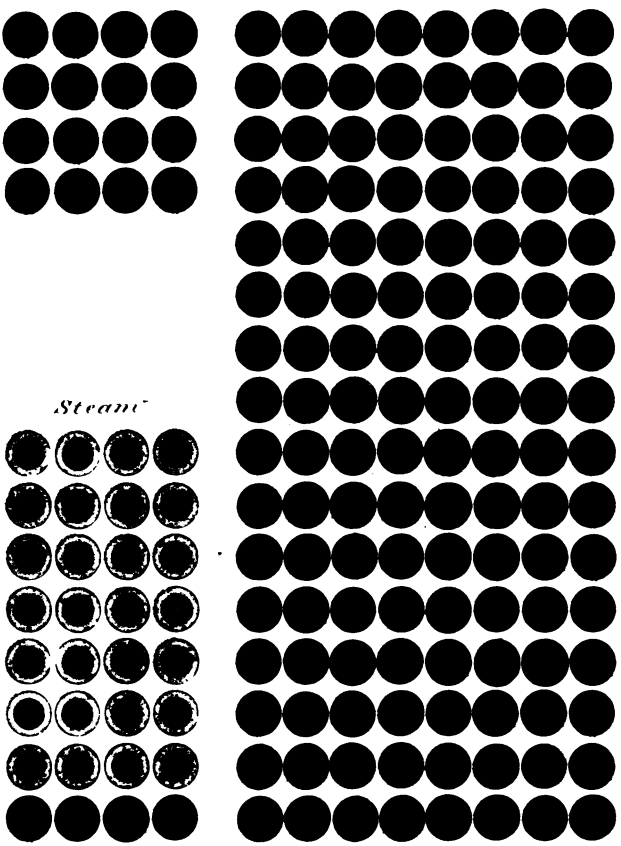
Fig. 3.

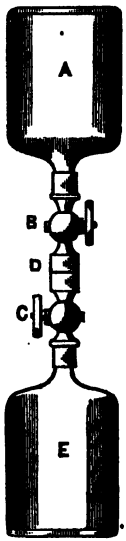
Products of the Combustion of a given Volume
of Carburetted Hydrogen and its equivalent
of Atmospheric Air.





examination will show (1 Fig. 23) that a portion of the heavy carbonic acid has ascended into the jar A, while a portion of the hydrogen has descended into the jar E, and each jar contains an equal quantity of each gas. This is the precise degree of incorporation which we desire to bring about between the coal gas and atmospheric air. We see, then, that gaseous bodies, unlike liquids, are constantly active in diffusing themselves throughout each other, until an equilibrium is produced; and that this action goes on without regard to the specific gravities or comparative densities of the bodies, except so far as they *retard* or *accelerate* the effect. It would seem, then, that if air were admitted to the coal gas in the furnace, nature herself would produce the required diffusion, and this would doubtless be true, if *sufficient time* were allowed; for it must be remembered that the diffusion of gases is not instantaneous but gradual, as may be seen in the case of a jar half filled with carbonic acid and half with oxygen. If a lighted candle be carefully lowered into this jar, it will burn near the top with great brilliancy, while near the bottom it will be immediately extinguished, a result proving that the two gases are not yet perfectly mingled.

FIG. 23.



Slow Rate of Diffusion.—The rate of diffusion of gases has been made a subject of careful experiment and calculation. In one of our standard works on Physics we find the following: "When different gases are brought together, they mingle with each other gradually, offering no other resistance to the mixture than the opposition which pebbles present to the motion of water." Here we have the advantage of small quantities, definite proportions, and deliberate mixture of the masses to begin with, yet we find that the operation is a

[1] Fig. 22, near the bottom of page 122, should read "Fig. 23;" and one hundred and twenty atoms, near the bottom of page 121, should read one hundred and twenty-*eight* atoms.

gradual one. A well known work on chemical manipulations directs that the oxygen be well mingled with the hydrogen, and that they be permitted to remain for a considerable length of time before firing. Here are deliberate and pains-taking measures for securing a perfect incorporation of the gases, when only a vial full is to be used. In another standard work on Chemistry, we find the following statement: "If a receiver be filled with seventy-five volumes of hydrogen, and twenty-five of carburetted hydrogen, agitated, and allowed to stand over water for twenty-four hours, the mixture will be as perfect as possible." In another work we are told that in making mixtures of gases, although they will become uniform *if sufficient time* be allowed, yet "this period will be very long, extending over several hours, when the vessels are narrow; even in a wide jar, several minutes are required for complete mingling."

Law of Diffusion.—While time will accomplish complete diffusion, yet the effect of varying densities or specific gravities in the gases is of sufficient importance to receive our notice. It has been found that the rapidity of diffusion is dependent on the relative densities of the gases, and it appears that the velocities with which gases diffuse themselves are in inverse ratio to the square root of their specific gravities. The following table gives the specific gravities of the several gases met in the furnace, the square roots of their densities, and the reciprocals of these roots, or their rates of diffusion.

Names of Gas.	Sp. Gravity.	Sq. R. of Sp. Gravity.	Rate of Diffusion.
Hydrogen,	.06926	·02632	3.7994
Oxygen,	1.1056	1.0515	.9510
Nitrogen,	.9713	.9856	1.0147
Carburetted Hydrogen,	.559	.7476	1.3375
Bi-carburetted Hydrogen,	.978	.9889	1.0112
Carbonic Oxide,	.9678	.9837	1.0165
Carbonic Acid,	1.52901	1.2365	.8087

Impediments to the Required Association.—Here are no less than seven diffierent kinds of gases, all of which come in contact with each other in the furnace, struggling

together, yet all tending, according to the law of diffusion, toward perfect incorporation. These bodies, as we have seen, vary in specific gravity, from hydrogen, which is the lightest of all known substances, to carbonic acid, one of the heaviest gases. This is one of the most important natural impediments to the formation of that perfectly uniform mass, which is essential to complete combustion. The most abundant of any of the gases found in the furnace are atmospheric air and carburetted hydrogen. In the above table we see that the air[1] has nearly double the density of carburetted hydrogen with which it is to mingle, one hundred cubic inches of the carburetted hydrogen weighing only seventeen grains, while the same volume of air weighs thirty-one grains; the contrast is still greater between air and hydrogen, the air being nearly fifteen times heavier than hydrogen. These are the elements and compounds which are expected to become thoroughly incorporated in the furnace.

Velocity of the Air through the Furnace.—A furnace which consumes only two hundred pounds of coal per hour, requires, for the gaseous portion of the fuel alone, ten thousand feet of air, and this is to be thoroughly mingled with one thousand feet of coal gas. As the grate is constantly kept covered with coal, all this large volume of air must pass up between the lumps of coal, consequently, the velocity of the current must be greatly increased to supply the required volume.

Dr. Ure estimates that the quantity of air passing through an ordinary fire-chamber may be regarded as double that which is actually necessary for combustion, and the proportion of carbonic acid generated, therefore, is but half of what it would be were all the oxygen combined. The increase of weight in such burned air of the temperature of 212° being taken into account, it will require fifty-seven feet per second for the required velocity in a chimney, one hundred yards high. This estimate is over-rated, as there are many circumstances which have a tendency to diminish the

[1] The specific gravity of air is 1.000.

velocity. But Dr. Ure found by experiment that the velocity in a chimney only forty-five feet high, and with a mean temperature as low as 270°, to be between six and seven feet per second.

If it requires a long time, at least several minutes, for a mere jar full of gases to become duly mingled, and that too when free from all disturbing influences, how can we resist the conclusion that it is impossible for the large volume of heterogenous gases to mingle in the furnace, while moving in the same direction at the rapid rate which we have seen.

How Coal Gas Escapes Combustion.—The heated and rarified coal gas rises, as it is generated, by its own levity, the air rushes up to fill the vacuum, and hence these masses cannot come in contact, except in strata, for by the law governing the motion of bodies, matter put in motion by one force, cannot change its direction without the application of some other force. Therefore, it is evident that the rapid velocity of the currents in a furnace are antagonistic to the lateral or circular motion which is essential to diffusion.

The junction of the Mississippi and Missouri rivers forms a striking illustration of the effects of currents in obstructing mixture. On account of the mineral matter which each holds in solution, the water of each is sufficiently colored to distinguish the one from the other, and these waters run side by side in the same channel for miles before they blend.

Structure of Flame.—That currents of inflammable gases do not mingle rapidly with air may be shown by a variety of experiments. If some alcohol be ignited in a small cup, and a stick of white pine wood be placed across the top for a short time, the stick will be blackened at only two points, and these will be the points where the flame is in contact with the air, which shows that the flame is only a thin shell or film of white hot vapor. Again, take a bit of phosphorus, one of the most inflammable of all substances, place it in a pendent spoon, ignite, and introduce it into the middle of this flame, and it will be immediately extinguished,

while the moment it is withdrawn, and comes in contact with the air, it will re-kindle. Why does it not burn while in the centre of the flame? Simply because there is no oxygen there. Although this small volume of flame from the alcohol is entirely surrounded with air, still the gaseous hydro-carbons arising from it, mingle with the air only so far as to produce a little thin film of flame around the outside of the main volume.

The common candle or lamp furnishes a still more convincing illustration of the reluctance which the air exhibits in mingling with inflammable vapors.— Place the end of a small tube in the centre of the flame of a burning candle, as shown in Fig. 24, a small stream of cloudy vapor will escape at the opposite end, and ignite on applying a match. This is a hydro-carbon, and does not differ essentially from the coal gas generated in the furnace; this does not burn in the centre of the flame, because no oxygen comes in contact with it. If a piece of mica be held in the flame until it is at a white heat, a ring of light is seen around a dark central space, which shows that no combustion is going on in the centre, but that the mingling of the air and vapors is confined to a thin shell or film. Upon this point all authorities agree. Dr. Reid tells us that the flame of a candle is produced by gas formed around the wick acting upon the oxygen of the air, the flame being confined to the exterior portion of the ascending gas. All *without* is merely heated air or products of combustion; all *within* is unconsumed gas, *waiting its turn to mingle* with the oxygen of the atmosphere. Mr. Brande observes that the combustion of the candle is superficial, the flame being only a thin film of white hot vapor, enclosing an interior portion which cannot burn for want of oxygen. On page 151, Vol. 8, of Berzelius'

Fig. 24.

works, we find the following:—[1] "Si l'on considère la flamme d'une chandelle, on voit qu'elle se compose de plusieurs parties dont on peut aisément distinguer quatre. A sa base, on aperçoit une petite partie d'un bleu foncé, qui va toujours en diminuant à mesure qu'elle s'éloigne de la mèche, et qui disparoit tout-à-fait là où les côtés de la flamme s'élèvent verticalement. Au milieu de la flamme, est une partie obscure qu'on aperçoit au travers de la partie brillante. Cette partie renferme les gaz émanés de la mèche qui, *n'etant point encore en contact avec l'air, ne peuvent pas bruler.* Autour d'elle est la partie brillante de la flamme. En outre, lorsqu'on regarde avec quelque attention, on voit sur les confins de celle-ci une mince enveloppe peu lumineuse, qui devient plus large vers le sommet de la flamme. C'est là que la combustion des gaz s'opère, et *que la flamme est la plus chaude.*"

We might also quote Sir Humphey Davy, Prof. Daniels, Dr.. Thompson, Faraday, and Tyndall, in corroboration of the main facts here stated. All these authorities have furnished us with illustrations sufficient to fortify the following inferences:—

1st. That the dark cone observable in the centre of the flame, is a body of highly heated inflammable gas.

2d. That it is ready for combustion, and is only waiting its turn to become mingled with the oxygen of the air.

3d. That the portion of gas which becomes sufficiently mingled with oxygen is confined to a very thin shell surrounding the dark central cone.

4th. That surrounding this shell or film is a faintly luminous envelope which contains the products of combustion.

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[1] If we consider the flame of a candle, we see that it is composed of several parts, of which we can easily distinguish four. At its base, we perceive a small portion of dark blue, which diminishes as it recedes from the wick, and which entirely disappears where the sides of the flame rise vertically. In the middle of the flame is a dark point seen through the brilliant portion. This contains the gases evolved from the wick, which, *not being yet in contact with air, cannot burn.* Around this is the brilliant portion of the flame. Moreover, when we observe with attention, we see, on the borders of this latter, a thin envelope, faintly luminous, which widens toward the summit of the flame; it is there that the combustion of the gases takes place, and that the flame is hottest.

5th. That the inflammable gas in the centre cannot burn because little or no air reaches it, and the air which does penetrate so far, has given up its oxygen in passing through the thin shell where combustion is going on.

[1] "Quant à l'espace conique interne, il est rempli de gaz combustibles qui ne peuvent pas y bruler, parce que l'air qui parvient à pénétrer jusque là, a dejà perdu la plus grande partie de son gaz oxygène."

The three distinct cones observable in the burning candle are represented by Fig. 25. The central cone, *a*, is composed entirely of the combustible gases produced by the decomposition of the tallow. Surrounding this, is the cone *b*, in which the hydrogen unites with the oxygen, and the atoms of the carbon are left to float about in a state of incandescence, which gives a vivid white light. Around the second cone is the dark exterior cone, *c*, where the oxygen of the atmosphere unites with the carbon. At the base of this exterior cone a dark blue light may be observed. At the point a sufficiently large number of atoms of oxygen ascend and penetrate a portion of the combustible gas, to consume its carbon and hydrogen simultaneously, giving the atoms of carbon no time to radiate light, which accounts for the dark color. We often see gas lights almost extinguished in railway stations and public halls where they are exposed to sudden currents of air. When the wind blows, the oxygen is carried to the very centre of the flame, which consumes the hydrogen and carbon at the same time, and this causes the vivid white light to change instantly to a pale blue.

FIG. 25

"Nothing," says Dr. Ure, "places in a clearer light the heedlessness of mankind to the most instructive lessons, than their neglecting to perceive the difficulty of duly intermingling air with inflammable vapors for purposes of their

[1] As to the inward conical space, it is filled with combustible gas, which cannot burn there, because the air which succeeds in penetrating so far as that, has already lost the greater part of its oxygen.

combustion, as exhibited in the every day occurrence of the flame of a tallow candle, or common oil lamp; for though this flame be in contact, externally with a current of air created by itself, yet a large portion of the tallow passes off unconsumed, with a great loss of heat and light which they are capable of producing."

If so small a volume of gas as is obtained from the wick of a candle, which has free access to the air on all sides, finds difficulty in coming in contact with an adequate supply of oxygen, how can we expect the enormous bulk of gas generated in the furnace to effect the required mixture when the supply of air is restricted to one side, and the whole under the opposing influence of a strong upward current?

Why Spirits of Turpentine Smokes.—Spirits of turpentine is a pure hydro-carbon, but if we attempt to burn it in a common lamp it sends off a large volume of dense black smoke. Why is this? Because this substance is rich in carbon; it contains five equivalents of carbon for every four of hydrogen. The atoms of carbon, which are set free as the hydrogen enters into union with the oxygen, are so numerous that they cannot find sufficient oxygen to convert them into carbonic acid, before they have passed beyond the temperature of ignition. This may be shown by holding a metallic substance, as a knife or spoon, in the flame of a common candle; the metal conducts away the heat and cools the flame which comes in contact with it, so that atoms of carbon in the immediate vicinity have not sufficient affinity for the oxygen to form carbonic acid, and hence they are deposited on the metallic surface as soot. What takes place, on a small scale, in the flame of a smoking candle, or lamp of spirits of turpentine or petroleum, takes place in the furnace on a large scale. The volatile hydro-carbons are not duly mingled with a sufficient supply of air before they have passed beyond the point required for ignition; hence, they pass away as invisible vapors, or become partially consumed, in which latter case, as the hydrogen burns first, a large volume of dense smoke is produced.

CHAPTER V.

On the Construction of Furnaces Adapted to the Complete Combustion of Fuel.

Combustion Incomplete in Ordinary Furnaces.— Keeping in view the numerous and convincing illustrations of what nature requires, as exhibited in the preceding chapter, it is evident that the construction and arrangement of any furnace, which has for its object the complete combustion of fuel containing volatile hydro-carbons, must be based upon the following principles :—

1st. Of furnishing an adequate supply of air.

2d. Of permitting the air to be carried to the fuel in different parts of the fire-chamber in a pure state.

3d. Of producing an intimate mixture between the air and the inflammable gases before they have passed beyond the point where the temperature is sufficient to induce chemical action between the combustible and the supporter.

It demands no very close scrutiny or keen observation to discover that a furnace, constructed on the ordinary plan of admitting the air, *en masse*, through the grate, fails to meet any one of the foregoing conditions. The bars, or grate, are always, or should be, covered with a mass of incandescent coke. When a fresh charge of coal is thrown into the furnace, the passage for the air through it must be more or less closed, therefore, the supply of air for the time is greatly diminished; but this is the very time when there is the

greatest demand for a larger supply of air, for the moment the fresh coal comes in contact with the highly-heated coke, it absorbs heat, and large quantities of inflammable gases are set free, for the combustion of which a large volume of air is required. Thus, the *smallest* quantity of air is unavoidably admitted at the time when there is a demand for the *largest* supply, and unless this deficiency is supplied from other sources, the coal-gas generated by abstracting heat from the incandescent carbon on the bars must escape unconsumed.

This gas, as we have seen, consists mainly of carburetted hydrogen, yet contains a per centage of pure hydrogen, of bi-carburetted hydrogen, and of carbonic oxide, all of which are the best of inflammables for the generation of steam. Not only are these valuable heat-giving commodities lost, but it would have been better had they not existed in the coal, as their production renders latent a large amount of heat, which at times almost paralyzes the effective operation of the furnace.

"When a fresh supply of coal is put on a briskly burning fire, the first thing which takes place is, that the coal softens and swells, attended with the evolution of a large quantity of carburetted hydrogen gas, requiring for its combustion a correspondingly large supply of atmospheric air,—the coal undergoing in fact, in the first stage of combustion, just the same process that it does in the retort in the manufacture of gas, which in the latter case is preserved and found so valuable a commodity, here escapes unconsumed up the chimney, not only furnishing no heat itself, but abstracting from the heat arising from the combustion of the carbonaceous portions of the fuel, the heat for its own gasification, a circumstance which readily explains the fact that more heat is practically obtained in many kinds of furnaces from coke, (or, in other words, coal deprived of about one-third part, by weight, of that portion of its combustible matter which is richest in furnishing material for heat,) than from coal in its pure state, with all its hydrog-

enous portion intact. From the same cause,—viz., the imperfection of our furnaces,—the commercial value of coal is often in the inverse ratio to the quantity of its bituminous constituents, and its real heat-giving powers, had we the capacity to render them available. It can not in fact be otherwise; for a furnace, immediately after a fresh supply of fuel, requires more than double the quantity of air it did the instant before, while we have no contrivance for furnishing such a supply, although without it, throughout the space of time during which rapid gasification of the hydrogenous portions is going on, more than half the fuel consumed is wasted, and passes off unburned, becoming thereby not only totally unproductive in itself, but absolutely an agent of evil, by robbing the furnace of the heat absorbed in its own volatilization."[1]

When too limited a supply of air is admitted for the complete combustion of either carburetted or bi-carburetted hydrogen, the hydrogen unites with the oxygen and is converted into water, while the carbon is deposited in the form of smoke or soot; or it may find sufficient oxygen to become converted into carbonic oxide, and partly into carbonic acid.

"When carburetted hydrogen is kindled, and just as much oxygen admitted as will consume its hydrogen, the carbon does not burn at all, but is sent off in the form of smoke or deposited as soot."

After the volatile hydro-carbons have been driven off, the supply of air demanded is very much diminished, and, after the body of coke has become thin on the bars, the passages for air may become so large that a great *excess* of air is admitted, which retards the rapidity and intensity of chemical action, by its cooling effect, and also absorbs heat in passing through the fire-chamber, so as to lower the general temperature, and thus prevent the rapid generation of steam.

There is another difficulty in the way of furnishing a due supply of air from the base. As the volatile matter is

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[1] Prideaux on "Fuel."

expelled, the process "of coking" commences, and continues until a mass is formed almost impervious to air; so that its passage into the furnace through the grate is in a great measure cut off. The same difficulty is encountered in using coal of a smaller size, shavings, saw-dust, tan-bark, etc. The heat will drive off the inflammable gases, and, as little or no air can pass through the solid mass from below to mingle with them, they are lost. Even after the coal gas has been driven off, an insufficient supply of air will cause the formation of carbonic oxide, as explained on page 107. Thus it appears that the very first indispensable requisite to complete combustion, viz: a supply of air proportionate to the wants of the fuel during the different stages of the process, *cannot be furnished by a furnace of ordinary construction.*

The Air cannot reach the Gas in a State of Purity.—Let us now inquire how far an ordinary furnace will satisfy the second condition, viz: the supplying of *pure, uncontaminated* air to all portions of the fuel, whether solid or volatile. A very simple illustration on this point will suffice. Hold a small piece of paper over the chimney of a common kerosene lamp—it will not ignite. Why not? Not for the want of heat; not for a deficiency in the supply of air, for there is a rapid current constantly passing through the chimney; but because this air has given up its oxygen to the hydro-carbons which came from the oil. This air will not support combustion, as it consists chiefly of nitrogen and carbonic acid. Would any one think of using this to support combustion in another lamp? But would it be any more unphilosophical to do this than to use the air which has been vitiated by passing over incandescent carbon, for the combustion of a large volume of coal gas? But this is just what is done in ordinary furnaces, and instead of the volatile portion being burned, it is driven off unconsumed, oftentimes accompanied by a huge volume of dense smoke. If kindling wood be thrown upon the top of a fresh charge of coal in a common stove, it does not take fire, because the air which has passed through the mass of

coal has lost its oxygen; even a small piece of paper can scarcely be lighted; how then can we expect there will be a sufficient amount of air present to burn a large volume of gas?

Mixture Incomplete in Ordinary Furnaces.— The difficulties of duly mixing the air and coal-gas were fully illustrated in the last chapter, (*Vide page* 127,) and if we consider that the air in an ordinary furnace is admitted at a single aperture, and moves at a rapid rate in the same direction as the coal-gas, we can readily perceive the impossibility of bringing about that intimate association of atoms which the inexorable laws of chemical action demand.

From the foregoing facts and illustrations we arrive at the following conclusions;—

1st. That during the combustion of bituminous coal and many other varieties of fuel, large volumes of inflammable gases are generated.

2d. That, when these combustible hydro-carbons are intimately blended with a proper volume of pure air, and the mixture heated to a temperature essential to ignition, their elements enter into chemical combination with oxygen, producing a large volume of flame, and a high calorific effect.

3d. That the volume of inflammable gases is by far the largest, just after a fresh supply of coal is added.

4th. That this additional quantity of coal obstructs the passage of air through the grate, so that there is an inadequate supply.

5th. That this deficiency causes the escape of pure hydrogen, an invisible, combustible gas; of carburetted hydrogen, an invisible, combustible gas; of bi-carburetted hydrogen, an invisible, combustible gas; of carbonic oxide, an invisible, combustible gas; or the hydrogen of these compounds of carbon and hydrogen may be consumed, and the carbon changed from the invisible state of gaseous combination with hydrogen, to a black, pulverulent form, called smoke.

6th. That smoke may be produced by the admission of

too much air at a low temperature, as well as too little at a high or low temperature.

7th. That in furnaces as generally constructed, the air can reach these inflammable gases only by passing through the highly incandescent and ignited carbon, by which a portion, or all of its oxygen, is converted into carbonic acid.

8th. That this renders it incapable of effecting the combustion of the inflammable gases, mentioned in paragraph 5, whatever may be their temperature, or however abundant may seem to be the supply of air.

9th. That, even though a proper supply of pure air could pass through the grate to the inflammable gases, the time allowed for the current does not permit that thorough mixture required for chemical union between the oxygen and inflammable gases before they have passed beyond the temperature essential to ignition.

10th. That this circumstance will occasion the loss of all the inflammable gases mentioned in paragraph 5.

11th. That the coke, or solid portion, and those varieties of fuel containing little or no volatile matter, require that every part of the burning mass shall come in contact with pure air.

12th. That, in ordinary furnaces, this is impossible, as the upper portion can receive only contaminated air,—air which has given up a portion of its oxygen to be converted into carbonic acid.

13th. That, if there be a deficiency in the supply of air in any portion of the burning mass, carbonic *oxide*, instead of carbonic acid, will be produced, and even the carbonic acid which *is* produced in those parts of the fire chamber, which have a due supply of air, will, in passing over the heated fuel, be converted into double its volume of carbonic oxide, and escape unconsumed.

14th. That, whenever the escape of any combustible gas from the furnace occurs, two losses, at least, are sustained. First, the furnace is robbed of the large amount of heat required to raise this portion of the fuel from a solid to an aeri-

form state. Second, all the calorific effect will be lost which would have been produced had these inflammable gases entered into chemical union with oxygen.

15th. That the loss sustained in the form of smoke is very small, in comparison to that in the form of the invisible gases, carburetted hydrogen, bi-carburetted hydrogen, and carbonic oxide.

16th. That when pure hydrogen is allowed to escape at a high temperature it sometimes combines with nitrogen, producing a gas called ammonia, which is more destructive to fire than is water itself.

How these Losses may be Prevented.—Numerous inventions have come before the public for effecting "the combustion of *smoke*, and securing economy in the use of fuel." Our space does not permit of an examination of their respective claims. So far as our acquaintance with them extends, most of them are founded on the erroneous idea that if they can pass "the smoke," (combustible gases they mean,) over intensely heated bodies, it will be consumed. For example, we copy the following claims:—

"The body of smoke issuing from one fire is made to pass over and among the glowing coals of another, and thus is consumed."

"By bringing the smoke in contact with glowing, incandescent carbon it is consumed."

"The smoke emitted is drawn over the red hot fuel of the next fire place, by which means it becomes consumed."

While it is a leading condition of the combustion of any gaseous body that it be mingled with a proper supply of oxygen at a given temperature, nevertheless, these inventors have gone on the supposition that heat alone will effect their combustion, but, as has been shown, no degree of heat can consume carbon, carburetted hydrogen, or any other solid or gas. Indeed, heat has nothing to do with their combustion only so far as to induce chemical action between combustibles and the supporter when brought into contact. Heat may effect a *decomposition* of fuel, but *decom-*

position is not *combustion.* Heat may cause visible smoke and invisible carbonic acid to combine and produce invisible carbonic oxide, and thus the smoke *appears* to be consumed. But this is not combustion, it is a *heat absorbing* rather than a heat producing process. Because red hot bars of iron or "red-hot fuel," or "glowing coals" will burn a boy's fingers or a cat's nose, it is not a logical conclusion that it will burn carbon or carburetted hydrogen. The inflammable vapors in the central cone of the candle (page 129) were hot enough, but for the want of oxygen were incapable of burning. Any method, which can bring any of the combustible products of imperfect combustion into chemical union with oxygen, will prove efficient in correcting the evil.

Reason Why some Lamps Smoke.—But why create an evil and then devise a remedy? why not first find the conditions necessary for perfect combustion, and construct a furnace which shall meet these conditions, instead of half burning the fuel, and then undertaking the difficult task of burning the combustible products of an imperfect combustion? When the flame of a lamp is dull and red, and sends off a volume of black smoke, do we set ourselves to work to burn that smoke? Who ever heard of a lamp burning its own smoke! When petroleum first came into use, it could not be burned in an ordinary lamp; it sent off a dense volume of smoke, and created an intolerable odor. The cause was ascertained, and the construction of the lamp so modified as to render its combustion so complete that it is now regarded one of the finest illuminators in the world.

Cause of Smoke in the Lamp and Furnace Identical.—*There is a deficiency in the supply of pure air at the time,* at the *place,* or in the *manner,* that will enable the elements of the hydro-carbons to enter into chemical union with oxygen. If the arrangement of our lamps could be so changed as to prevent these evils, it remains to be proved why the construction of our furnaces can not.

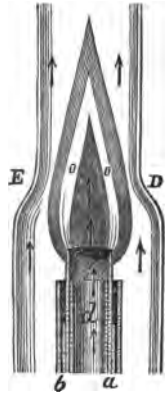
Dr. Franklin proved that two small wicks placed in two

candles, and burnt side by side, will give more light than if they were combined and placed in one candle. Very large wicks convert the oil of a lamp into gas faster than the air can consume it.

Camphene and kerosene are superior illuminating substances, but they cannot be burned in the ordinary way, because they contain so large a proportion of carbon that they smoke excessively. This is the case with the furnace; a proper supply of air cannot mingle with the inflammable gases before they have passed into a region where the temperature is too low for their chemical union with oxygen.

Argand's Invention.—Ami Argand, of Geneva, conceived a plan by which this evil may be remedied so far as lamps are concerned. He made the wick hollow, so as to burn in a ring or circle, and thus admitted a current of pure air to the inside of the flame, whereby this dark central cone of unburned gases is avoided, and the surface of contact with air nearly doubled. This is represented in Fig. 26, as if the flame were split down from the top to the bottom, forming a vertical section. D and E represent the chimney; *a* and *b* show a circular wick arranged between metallic tubes, through the center of which a draft of air, *d*, rises, as shown by the central arrows, the light conical space *o o*, is filled with inflammable gases, and comes in contact with the air, both on the outside and inside, so that there is nearly double the contact surface that there is in ordinary lamps. Petroleum, and other oils, which, in an ordinary lamp, produce a long, conical flame, of a dull, murky red color, burn in this lamp with a short, white and intensely brilliant flame. Cut off the supply of air from the interior, and, notwithstanding a free supply of air on the exterior, the flame becomes instantaneously dull, red and smoky, with little heating or illuminating properties.

FIG. 26.



Now the cause of this imperfect combustion is not a want of air, but the slow rate of mixture occasioned by the want of an adequate amount of contact surface between the inflammable gas and oxygen. By preventing the admission of air to the center of the flame, the gases generated from the inside of the wick are decomposed by the white hot flame which surrounds it, but no air reaches them there, they ascend rapidly, and, before they can become mingled with a sufficient quantity, they are reduced to a temperature too low for chemical action, and, hence, pass away unconsumed, —the hydrogen as an invisible gas, and the carbon in a state of minute solid particles, or true smoke. When the air is admitted to the *inside*, the accessible contact surface for the clashing of atoms, is nearly doubled and the long smoky flame instantaneously becomes short, white and highly luminous, with a great increase of heat for the same expenditure of oil. The most powerful lamp furnace in use for the laboratory is constructed upon this principle. The mouth blow-pipe is an instrument used for carrying a supply of oxygen to the interior of the flame, by which the heat is powerfully augmented. The common Argand burner has been applied to the use of illuminating gas, and its illuminating powers greatly increased by causing the gas to come in contact with the air in a series of jets, thus affording the largest possible contact surface for the mingling of the atoms of combustible gases with those of atmospheric air. This mode of bringing the gases to the air has become universally recognized and proved to be an invention of lasting value to mankind, as will any invention which is founded upon scientific principles and capable of producing a desirable result.

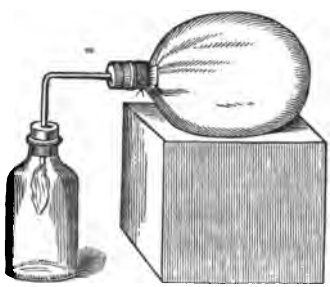
Sidney Smith's Method of Effecting the Complete Combustion of Fuel by the Admission of Air to the Fire-Chamber in Small Jets.—What Ami Argand did for the lamp, Sidney Smith has done for the furnace. During the winter of 1866, having become convinced of the enormous waste of fuel in our *common furnaces*, and having

observed the satisfactory results obtained in the Argand and other lamps by this method of presenting a large surface for contact between the atoms of combustibles and of the air, he conceived the idea of effecting the combustion of fuel in a similar manner.

Accordingly, he procured an iron cylinder, perforated throughout its entire surface, and surrounded it with a perforated wall, in such a way as to leave between them a narrow air chamber. He then placed the whole inside the fire-chamber of an ordinary stove, and filled the perforated cylinder with wood and coal. After this had become fairly ignited, he closed the base of the stove, and thus prevented the admission of air to the fire-chamber, except through the perforations of the two walls. He then threw in a fresh supply of light fuel, and, to the surprise of all present, gas from the fuel burst into a jet of flame at every orifice, shooting towards the centre of the cylinder, completely filling it, and even bursting through the door into the room. By the use of coal in the same rude piece of apparatus, heat was obtained of sufficient intensity to melt iron. The fact that jets of flame were produced even at the height of a foot from the fuel, proves beyond a question that, in the ordinary modes of combustion, large quantities of combustible gases are generated and allowed to escape unconsumed.

Experiment.—Fill the gas bag, Fig. 27, with coal gas; pass a small stream from it into the jar of oxygen, and it will burn with an intensely luminous flame.—This is the process in the Argand gas-burner, which mingles the gas with the air by passing it to the air. Now fill the bag with oxygen and the jar with coal gas; pass a small stream of oxygen into the jar, to which apply a lighted match. The oxygen will burn, that is, enter into chemical union with the other elements, producing a brilliant flame,

FIG. 27.



Coal Gas Burning in Oxygen.

as in the former case. Again, fill the bag with air, and its oxygen may be inflamed in the same way; but on account of the large proportion of nitrogen, it burns with less brilliancy. The latter is the case in the furnace. The perforated cylinder is filled with volatile hydro-carbons, which come from the decomposition of the fuel, and the air passing in by hundreds of small streams, instead of one, produces the large number of jets of flame. This is another illustration of the principle which has been enforced all the way through this treatise, namely: that combustion is simply chemical union, that it is not essential how the elements employed are brought together, provided there is a contact of atoms, and that neither of the elements are *consumed*, (that is, destroyed,) but simply unite to form new compounds, and through this combination heat is developed.

On several occasions while watching the process of combustion, during its different stages in this experimental furnace, at that period when the hydro-carbons had just undergone combustion, and the highly-heated carbonaceous matter was remaining on the grate, we observed the phenomenon of a peach-colored flame, mingled with one of a pale blue color. The former, we think, must have been produced from the burning of cyanogen; the latter was undoubtedly due to the presence of carbonic oxide. It is hardly necessary to add that without a proper supply of atmospheric air, these gases would have escaped by the chimney, and so have been lost for calorific purposes.

Having witnessed numerous experiments upon the practical application of this new mode of effecting combustion, we avail ourselves of this opportunity to make some observations on the efficiency of the same. It has been successfully applied to heating furnaces of different sizes from the small parlor stove to one of sufficient capacity to warm an ordinary private dwelling. Its recent application to steam boilers of different forms and capacities has been made with such decided success as to leave no doubt in the mind of

the inventor respecting the important practical results to be obtained.

To enable the reader to fully understand the construction of the apparatus, and its mode of operating under steam boilers, correct drawings of the different parts are here inserted with accompanying descriptions.

FIG. 28.

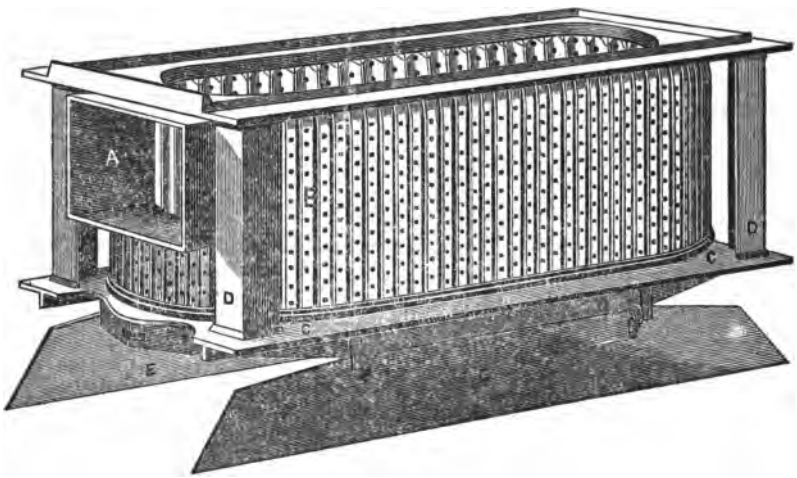
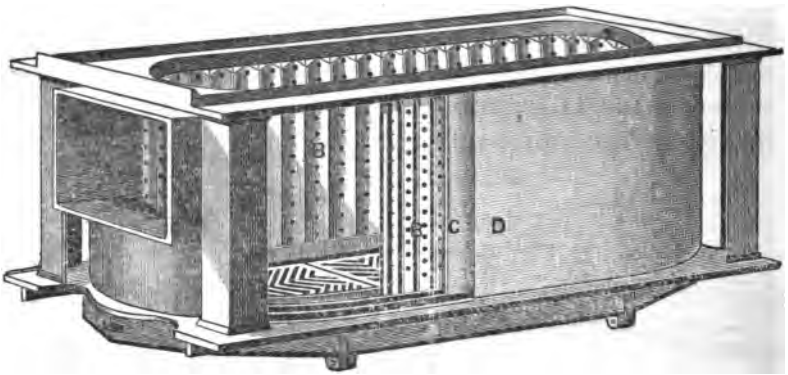


Fig. 28 represents the fire-chamber, with the front and exterior walls removed. A, the mouth-piece for the admission of the fuel. B, the interior wall of cast iron perforated throughout its whole extent for the admission of air to the fuel. This wall is composed of corrugated sections, about three inches in width, and one and a quarter inches in thickness. C C, the base. D D, the pillows supporting the cap which holds the upper ends of the sections in their place. E E, the trap in two sections,—now open. This opens for the purpose of removing the ashes and for drawing the fire.

Fig. 29.



In Fig. 29, the fire-chamber is represented with the trap closed. A portion of each of the three perforated walls is removed, showing the interior of the fire-chamber, the grates and the spaces between the walls. B is the interior wall, the same as seen in Fig. 28, B. C is a wall of thin metal, more finely perforated than B, and surrounding it at a distance of about three-eighths of an inch. This is kept in place by a flange on the base and cap of the fire-chamber. D is a second wall of thin metal with perforations still finer than those of C. This is separated from C three-eighths of an inch, and kept in place by a second flange on the base and cap. This gives us three perforated walls with air chambers between, entirely surrounding the fuel, and through which air is admitted for combustion.

Fig. 30.

Fig. 30 represents the base with all the other parts removed. A is the inner flange; B, the outer flanges for

holding in place the two exterior perforated walls. The channel between A and B is for the reception of the lower ends of the upright sections which compose the interior wall. C C are the brackets for supporting the grate. The grate is made in sections, one of which drops for the purpose of drawing the fire.

FIG. 31.

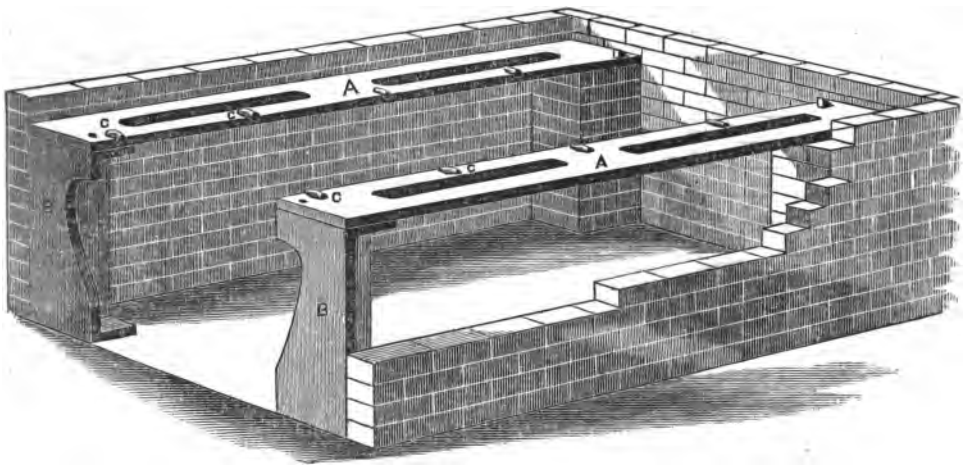


Fig. 31 represents a portion of the brick work, and cast iron ways, A A, on which the fire-chamber rests. B B are cast iron supports for the front ends of the ways. C C are rollers to facilitate sliding the fire chamber into place. The small holes represented in the front ends of the ways are for hooked bolts to secure the front to its place.

FIG. 32.

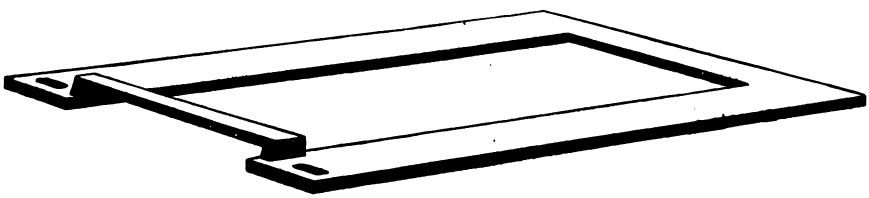


Fig. 32 represents the cap which is set in the brick work above the ways, at a distance exactly equal to the height of the fire-chamber.

FIG. 33.

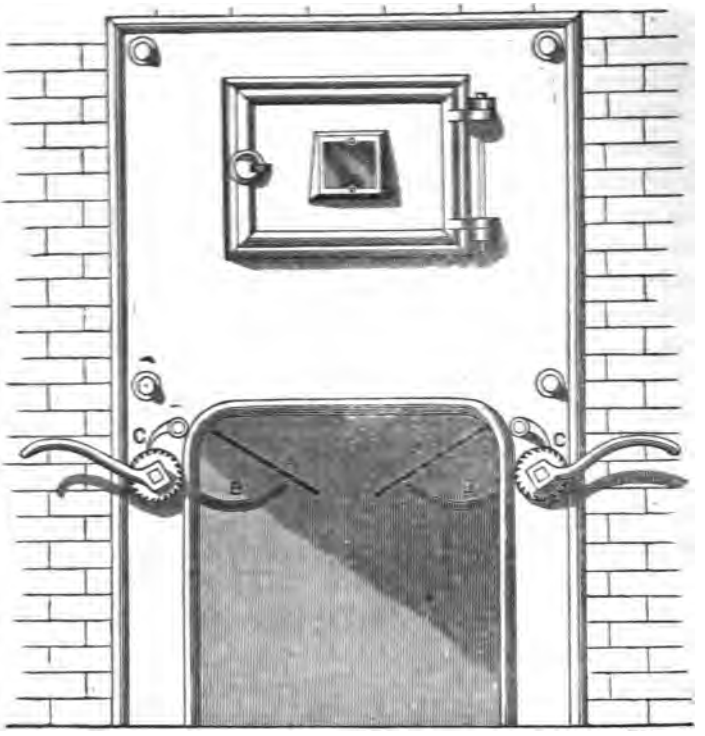


Fig. 33 represents the front. The door at the top is for the admission of fuel The opening seen below is the ash pit, in which may be seen an end view of the two sections of the trap A A. B B are the cams for raising and holding the two sections in position. These are moved by the two levers seen on the outside, and held in place by the palls and rachets C C. The holes seen at the upper corners, and in the centre, are for the admission of bolts, which secure the entire front to the wall.

Let us now suppose the several parts put together, ready for operation. On kindling a fire with both sections of the door open, as seen in Fig. 28, the air is admitted through the grate as in an ordinary furnace. When the

interior of the fire-chamber becomes heated, decomposition of fuel commences, combustible gases are set free, a portion of which will escape unconsumed; close the base, and the admission of air to the fuel is cut off, except through the perforations of the several walls. When the combustible gases are set free, and rise to the first series of perforations, the atoms of oxygen obtained from the currents of fresh air coming in, in minute streams, seize upon the atoms of the gases which are at a high temperature, and these points are made the centres of flame. If all the gases are not consumed at the first series of orifices, they pass up to the next, and so on, so that none of the combustible gases are allowed to pass away unconsumed.

One of the most important conditions for perfect combustion is here met,—namely: that the supply of air is regulated by the demand. No more air will enter through any one orifice than can be absorbed by the gas with which it comes in contact. This is a very important point because an excess of air, beyond what is absolutely required for chemical union, must have an injurious refrigerating influence; but when all the oxygen of the air which passes through the perforations enters into chemical union, heat is constantly developed, so as to overcome the cooling effect of the air.

By passing the air in by jets, minute currents are created at those point where it is the hottest,—these of course are the points where combustion has already commenced. The heat also causes the combustible gases to rush toward the jets of flame, to take the place of the rarified products of combustion which are constantly driven away by the current.

When a fresh charge of fuel, containing any considerable proportion of volatile matter, is added, a sufficient supply of inflammable gases is produced to cause the whole interior of the fire-chamber to become filled with streams of brilliant flame, while sufficient air is admitted to the solid portion to keep it in a state of intense incandescence. The interior of the fire-chamber becomes highly heated, and in a short time

the heat is communicated, both by conduction and radiation, to the air chambers. The cold air in passing into the exterior chamber in small streams, comes in contact with a large surface of heated metal, and consequently becomes evenly and moderately heated. It now passes with considerable force through the second perforated wall and impinges against the exterior of the interior wall, which is seldom below a red heat. Here the air becomes sufficiently heated to prevent any serious cooling effects when it enters the fire-chamber.

It will be noticed that this air chamber entirely surrounds the fire chamber, and the interior wall is perforated throughout its whole extent. This meets the second condition for complete combustion, viz: that every part of the burning mass, whether solid or gaseous, must be brought in contact with *pure air,—air uncontaminated with the products of combustion.* By this arrangement we have the combustible gases and ignited carbon in the *inside* and *pure air* entirely surrounding these on the *outside*, while the hundreds of orifices serve to bring these elements in contact with each other. Just the instant the streams of heated air pass through the perforations of the fire chamber, the atoms of oxygen separate from the atoms of nitrogen and seize with terrible energy upon the atoms of combustible gases. The nitrogen and carbonic acid, together with water in the form of aqueous vapor, are thrown off between the jets of flame, and carried away through the escape pipe by the ascending current. By this method the great and almost insurmountable difficulty, of effecting the complete intermingling between the atoms of the air and gas, is entirely overcome. These jets of air also require a force or momentum which enables them to overcome the impediments arising from the varying specific gravities of the several gases. The heavier atmospheric air penetrates the mass of hydrogen and other light gases. These numerous streams of pure air passing in at right angles to the upward currents of inflammables, over the entire surface of the flame-bed, leave nothing to

be desired in completing the preparatory mixture which the inexorable laws of chemical action demand.

In the use of coke, anthracite coal or other carbonaceous varieties of fuel, the distribution of pure atmospheric air in a required quantity by these numerous jets prevents the loss of fuel by its escaping in the form of carbonic oxide.

It was stated under the subject of coal that large quantities of an inferior kind (technically called slack,) are obtained and thrown away. This material possesses all the chemical properties of the best coal, but by reason of its small size it lies so close together as to form a mass almost impervious to air. When, therefore, a fresh charge of this fine coal is thrown into the furnace, it closes the openings in the grate, and thus prevents, in a great measure, the admission of air, consequently there can be only a slow, smouldering combustion, with a loss of nearly all the volatile portions of the coal. This same difficulty is encountered in the use of shavings, saw-dust, and tan-bark; and in the case of many varieties of peat this is the chief drawback to its usefulness. "A free-burning fuel," says Professor Johnston, "must exist in compact lumps or blocks which so retain their form and solidity as to admit of a rapid draught of air through the burning mass."

The plan of introducing the air at the sides and over the entire mass of fuel furnishes a complete remedy for this difficulty, and combustion is so quickened as to compete in rapidity and intensity with the more costly kinds of fuel. Fuel, in a finely divided state, readily gives off a large volume of inflammable vapors, and by effecting a complete combustion of these, a superior amount of heat is obtained for the rapid generation of steam.

On filling the fire-chamber of this heating apparatus nearly half full of shavings, saw-dust or coal-dust, we have one of the finest exhibitions of the complete combustion of volatile hydro-carbons ever witnessed. These inflammable vapors are not perfectly colorless but have a light cloudy appearance, closely resembling the gas which is conducted

from the central cone of the candle, (*Vide page* 127.) These may be seen playing among the particles of fuel, and when they rise and come in contact with the jets of air, the interior of the fire-chamber is filled with hundreds of beautiful gas-lights which shoot toward and meet at the centre, so as to form one large volume of flame, which rises to the flues of the boiler,—an experiment by which steam may be raised in an almost incredibly short space of time.

It may be proper to remark that the apparatus here described was constructed for an experimental fire chamber, to be used with Harrison's boiler in one of the large manufacturing establishments[1] of this city. This furnace was in operation during the last exhibition of the Worcester County Mechanics Association, held in the City of Worcester, September 1866. The following extract from the report of the judges appointed by the Association, may interest those who desire to know how far the first attempt to harmonize practice with science was successful:

"The fuel is consumed in a cylindrical, square, or oblong fire chamber, perforated with small holes throughout its entire surface, and surrounded with treble perforated walls. No air is admitted to the fuel through the grate at the bottom, but it passes through the small holes in the sides of the fire pot, and mingles with the gases of the fuel as they rise, in such proportions as to produce chemical union, instead of allowing them to escape.

The same principle is applicable to steam boilers, the operation of which the committee had the pleasure of witnessing in one of the large manufacturing establishments of the city, where at least one half of the usual amount of fuel was saved in doing a given amount of work, as compared with the old style furnace and grate. Bituminous coal, leather shavings, dry wood, saw dust and other combustible materials were frequently introduced into the fire chamber, and the phenomenon thus produced was wonderful and surprising. On looking in, during the process of combustion, numerous spirals of blue and white flame of great brilliancy were observed issuing from the little air holes

[1] T. K. Earle & Co.'s Card Setting Manufactory.

towards the centre of the burning mass, thus producing a much larger volume of flame than can be obtained from the same fuel in any ordinary fire chamber. The combustion was so perfect that little or no smoke could be seen issuing from the top of the chimney.

From the experiments made in our presence with stoves and boiler furnaces, the committee cannot resist the conclusion that the principles of perfect combustion, theoretically and practically, has been satisfactorily demonstrated during the present exhibition. The committee awards for this invention a *Silver Medal*."[1]

Such is the great variety which prevails in the arrangements of boilers and the several kinds of furnaces as at present constructed, so different are they in size, length and description of flues, in proportions of fire surface, force of draft, and other circumstances, all of which have more or less influence, that the inventor must necessarily encounter numerous obstacles in adapting his apparatus to the various conditions and wants of each. While the general plan of structure is now the same as has been presented in the foregoing drawing, yet many modifications in respect to the form, size, material, &c., of the different parts, have been made, and further improvements are in progress.

In furnaces of a large size, there is difficulty in effecting the necessary diffusion at a proper temperature, arising from the very large volume of air required for the complete combustion of the volatile constituents of the fuel. This obstacle is completely overcome by dividing the fire chamber into two or more portions by an internal partition, or by the use of two or more separate chambers, each of which is complete in itself.

Another great obstacle to the absolute freedom from smoke, arises from the irregularity in the time and mode of

[1] This apparatus is now in successful operation in several large manufactories in this state, in Burlington, New Jersey, in Baltimore, and other places. Any information respecting the efficiency of the same,—the actual saving in the use of fuel, durability, cost, &c.,—may be obtained by addressing either the Earle Stove Company, Worcester, Mass; or the Iron Discovery Company, Burlington, New Jersey.

charging, and the consequent inequality in the quantity of gas generated. The two portions formed by the internal partition also furnish a remedy for this evil by providing for alternate charging, which reduces the volume of gas evolved and the consequent demand for air to manageable quantities.

In the use of some varieties of fuel, which are almost impervious to air, such as caking coal, saw dust, &c., it may be necessary to admit a portion of air through the grate, in order to carry forward the decomposition of the fuel with sufficient rapidity to furnish an adequate volume of flame for the rapid generation of steam. The quantity of air admitted through the base is nicely regulated by a proper adjustment of the trap, or by a valve in the door which closes the entrance to the ash pit. The air which passes through the several perforated walls to the interior of the fire chamber is supplied from chambers at the sides, which are entirely distinct from the ash pit.

Laying aside the numerous imperfections incidental to almost every experimental piece of apparatus, it will be obvious to the reader that the construction of this furnace and the principles upon which it is based are in strict conformity with the complex, chemical processes constantly going on in the furnace, and that it supplies such processes with the means necessary to its completion in the order which nature demands.

1st. It gives us complete control, in respect to quantity, over the admission of air to the solid or carbonaceous portion of fuel, which serves to regulate the volume of gas set free in any given time.

2d. It gives us a similar control over the admission of air to the gaseous portion.

3d. The air is introduced to the entire gaseous as well as upper part of the carbonaceous portion of the fuel, from a chamber wholly unconnected with the ash pit. No deterioration, therefore, of the air can take place by a loss of a portion of its oxygen or by its becoming mingled with the products of combustion, thus completely overcoming a very

serious impediment to complete combustion which exists in the ordinary furnace.

4th. The air is introduced at right angles to the current of combustible gases, which overcomes the obstruction to their incorporation with air, arising from their rapid upward motion.

5th. By introducing the air in *jets*, it acquires a momentum which enables it to penetrate the mass of combustible gases within the fire chamber, thus materially assisting in the process of diffusion.

6th. The air passing in jets at right angles to the ascending currents of combustible gases also serves to overcome the impediment to the complete mingling of the air and gases which arises from the varying specific gravities of the different aeriform bodies found in the furnace.

7th. By restricting the admission of air to small streams, no great *excess* of air can reach any portion of the gas beyond what is required for perfect combustion, thus preventing any serious cooling effect from the introduction of air to the furnace.

8th. By admitting the air in small streams the *largest possible surface* is presented for the diffusion and mutual contact between the atoms of the combustible gases and air, thus completing the required mechanical mixture before either has passed to the region where the temperature is too low for chemical action.

9th. By passing streams of air over the entire surface of the flame-bed, an excess of heat is prevented in any one locality, and a longer available extent of flame is also given to the boiler.

10th. The heat, which in furnaces of the ordinary construction is lost at the sides both by conduction and radiation, is in this arrangement used in heating the air previous to its introduction into the furnace.

11th. In large furnaces the internal partitions provide for the alternate changing of each separate chamber, by which means the volume of gas and air required for its combustion is rendered more constant.

These several heads embrace some of the more essential points of merit which this apparatus possesses over the ordinary furnace, in obtaining great perfection in the process of combustion, and consequently the maximum calorific effect for any given quantity of fuel.

The Relative Advantages of Hot and Cold Air. —The use of hot air, for purposes of combustion, is a point to which inventors have turned their attention, and concerning the efficiency of which, there exists among practical men a great diversity of opinions. In looking over the patent list, we find contrivances almost innumerable; such as calorific plates, hollow bars, hollow grates, etc., etc., each claiming credit for originality and efficiency in the use of heated air: but in no one of these claims do we find the inventor bringing forward, either principles which have received the sanction of good authority or stood the test of actual demonstration, in support of what they desire to establish. It is evident, therefore, that if heated air possesses advantages over cold air, its value, as yet, is an *undefined* one.

The aim throughout this treatise has been to point out to the practical man the principles on which alone the complete combustion of fuel can occur, and we again assert that the greatest economy in its use can be secured only when the scientific conditions of the process are clearly understood and made foundations of practice. These conditions have been defined and illustrated, and we are now to consider very briefly the question, whether we can best meet those conditions by the introduction to the furnace of cold or hot air.

There can be no doubt as to the fact that the average temperature of a mixture of air and coal gas in the furnace is higher when it is fed with air at 550° than at 60°, and since a high temperature is indispensable to combustion, we might naturally arrive at the conclusion that heated air would be more efficient in the process.

But what change has this air undergone in being thus

heated previous to its introduction to the furnace? No *chemical* change has taken place, but *mechanically* a very important change has been effected. It has been found that a given volume of air, on receiving one additional degree of heat, will be increased $\frac{1}{490}$ part, therefore, on receiving an addition of 490°, that is on being raised from 60° to 550°, its volume will be doubled. Now it has been shown that the efficiency of air in producing combustion is in proportion to the quantity of its oxygen which enters into chemical union with the combustibles. But this double volume of air contains, by weight, no more oxygen than it did previous to its expansion, consequently any given volume of this heated and rarefied air would seem to be less efficient for purposes of combustion than the same volume of air at 60°.

Again it has been shown that the main requisite for combustion is a complete atomic mixture between the air and coal gas, but on heating the air, its volume must be enlarged, its atoms must be thrown farther apart, and, consequently, the difficulty of perfecting the preliminary operation of mechanical mixture would be augmented. This difficulty is always encountered in the use of furnaces constructed on the plan of supplying the air for the combustion of both the fixed and volatile portions of the fuel from the ash pit; for the air in passing between the red hot bars of the grate and over the incandescent carbon, to the combustible gases, must necessarily become highly heated, and the consequent rarefaction of this air presents an additional impediment to its incorporation with the coal gas. As a remedy for this evil, some have suggested the introduction of currents of cold air over the fuel, either by a valve through the door, or by leaving the door ajar, but it is difficult to conceive how any practical benefit is to be derived from this arrangement, because the mass of cold air, coming in contact with the gases arising from the decomposition of the fuel, would have a tendency to reduce them to a temperature too low for combustion, particularly where the inflammable vapors issuing from the fuel are liable to be chilled by coming in contact

with the flues or boiler plates, which, being good conductors of heat, and having water on the other side of them, must produce a powerful refrigerating influence.

There is still another disadvantage in the use of cold air over the flame-bed. Unquestionably there is a demand for a larger supply of air just after a fresh supply of coal, but to pour in a large supply of cold air, just as the temperature has been lowered by the effect of this fresh charge of coal and sudden evolution of gas, would for a time overpower and almost completely paralyze the effective operation of the furnace. The truth of this may be verified at any time by opening the feed door of one of Harrison's boilers and watching the motion of the index on the steam guage. Thus reason and experience alike protest against the error of attempting to effect the combustion of the inflammable gases by the introduction of cold air *en masse* over the surface of the fuel.

Others have attempted to effect the combustion of these escaping gases by the introduction of large streams of heated air through tubes, pipes, etc. This plan is undoubtedly correct, provided we can devise means for introducing a sufficient supply, and bring about such a distribution of the rarefied air as to cause each atom of the combustibles to enter into chemical union with its equivalents of oxygen, but this we shall find very difficult where the quantities are large. When, however, the quantities are small, as in the case of the common candle, the energy of combustion, in rarefied air, fully equals or exceeds that which takes place in air in a more condensed state. While any given volume of rarefied air contains a smaller number of atoms of oxygen, than the same volume of condensed air, yet the smallness of their number is compensated for by the increased energy of their action. To establish this, Dr. Frankland made some very interesting and satisfactory experiments, an account of which may be found in the Philosophical Transactions of the Royal Society of London, volume 151. He procured a certain number of candles

and carefully weighed them. They were then allowed to burn for an hour in the valley of Chamouni, and the loss of weight was accurately determined. The same candles were taken to the summit of Mont Blanc and were allowed to burn an hour in a place properly sheltered from the action of the wind; on his return, he again carefully weighed the candles and found that the quantity of stearine consumed above was almost exactly the same as consumed below; this result he ascribed to the mobility of rarefied air at this great height. He proved this by showing that when we compress the air, although we augment the number of atoms in contact with the flame, yet in almost the same degree we diminish their mobility, and retard combustion. He condensed the air around the pale flame of a spirit-lamp and found that it was rendered as bright as that of coal-gas, and on further condensation actually caused it to smoke.

Since the gaseous products of combustion assume a larger volume in a rarefied atmosphere than in a compressed one, it cannot be doubted that the calorific effect of a flame must be diminished to some extent by rarefying the medium in which it is produced; nevertheless, this effect may be completely neutralized by the smaller amount of refrigeration caused by the rarefied air. To establish this point, a spiral of platinum wire was placed under the receiver of an air-pump, and heated to redness by a voltaic current; on exhausting the receiver, the glow of the platinum gradually increased nearly to whiteness. On readmitting the air, it again diminished to dull redness, showing that the refrigerating effect of rarefied air is much less than air at the ordinary pressure. Thus while the temperature produced within a given flame is reduced by rarefaction, the loss of heat to the air is less than in a condensed atmosphere, so that *the actual temperature undergoes little or no alteration.* The diminution of light in rarefied atmosphere is attributed to the admission of oxygen to the interior of the flame, in which particles of carbon are usually precipitated, and where the region of luminosity is situated.

That the admission of oxygen to the interior of the flame has this effect is shown in the use of wire gauze, and Bunsen's burner, where *heat*, and not light, is the object of the combustion of gas.

We have barely room for the following conclusions:

1st. As it has been shown that it is impossible to pass a sufficient quantity of air through the incandescent carbon on the grate for the complete combustion of the volatile portions of the fuel, it follows that any change wrought upon the air, which increases its volume, previous to its introduction to the *ordinary* furnace, cannot increase its efficiency.

2d. That the admission of a large volume of cold air over the surface, produces too powerful a refrigerating influence, to insure the complete combustion of the inflammable gases.

3nd. That in heating the air previous to its introduction to the furnace, it necessarily becomes rarefied.

4th. That while a given volume of rarefied air contains a smaller number of atoms of oxygen than the same volume of condensed air, yet it has been shown by experiment that, within certain limits, the more rarefied the air, the more complete the combustion.

5th. That this more complete combustion in rarefied air is chiefly due to the greater mobility of rarefied gaseous bodies, which must produce a *more rapid admixture* of the air with the combustible gases than would otherwise take place.

6th. That while this increased rapidity of mixture causes a diminution of light, yet it has been shown by experiment that the calorific power of rarefied flame is not diminished.

7th. That by the introduction of heated air in small jets over the surface of the fuel, a sufficient supply of oxygen may be admitted, a much larger contact surface given, a powerful refrigerating influence avoided, a more rapid admixture arising from the increased mobility of particles obtained, and, consequently, the whole process of combustion quickened in rapidity and intensity and rendered more complete.

GLOSSARY.

AERIFORM, from *aer*, the air, and *forma*, a form; having the form of air.

ALCOHOL; vide page 44.

ALKALI; a soluble body with a caustic taste, which possesses the power of destroying acidity.

AMMONIA; a volatile alkali, composed of one equivalent of nitrogen and three of hydrogen.

ANTHRACITE; vide page 32.

ATOMS; vide page 57.

BITUMINOUS, vide page 33.

CALORIC; an imaginary fluid substance, once supposed to be diffused through all bodies.

CAMPHENE; vide page 44.

CANNEL; vide page 33.

CARBON; an elementary, combustible substance, existing pure and crystalized in the diamond, and sometimes in the graphite, and forming the basis of animal and vegetable charcoal, and of coke.

CARBONACEOUS; containing or composed of carbon.

CAUSTIC; possessing the power of burning.

CHEMISTRY, -ICAL; the science which treats of the elements of matter; their properties, their laws of combination and decomposition.

CHEMICAL ACTION; vide page 49.

CHLORINE; a yellowish green gas of a pungent odor.

COHESION, from *con*, together, and *haereo*, to stick; vide page 52.

COMBUSTION, from *comburo*, to burn; a chemical combination, accompanied by the liberation of heat and light.

CONSTITUENT, from *constituo*, to put together; that of which anything consists or is made.

CONTRACTION, from *con*, together, and *traho*, to draw; the state of being drawn into a narrow compass.

CRUCIBLE, from *crux*, *crucis*, a cross; a small vessel of metal or clay, used by chemists and goldsmiths.

CYANOGEN; a colorless gas, composed of one equivalent of nitrogen, and two of carbon, possessing the odor of bruised peach leaves; it burns with a rich blue flame, fringed with purple.

DEPHLOGISTICATED; deprived of phlogiston.

DENUDATION, from *de* and *nudo*, to make bare; a term used by Geologists to denote the removal of earth, laying bare of rocks, &c., by the action of running water.

ELEMENT; vide page 50.

EMPYREUMATIC; possessing the odor of animal or vegetable substance when slightly burned in a close vessel.

EQUIVALENT; vide page 55.

GAS, -EOUS; a permanent, aeriform fluid.

HERMETICAL SEAL; when the neck of a glass vessel is heated to the melting point, and then twisted with pincers till the vessel is air tight, it is said to be hermetically sealed, or to have received the seal of HERMES, the reputed originator of Chemistry.

HETEROGENEOUS; different in nature and properties.

HOMOGENEOUS; alike in nature and properties.

HYDROGEN; an inflammable, colorless and odorless gas; the lightest of all known substances.

HYDROGEN; Carburetted and Bi-carburetted, vide page 67.

HYDRO-CARBON; a term applied by chemists to certain compounds of carbon and hydrogen.

HYPOTHESIS; a supposition assumed to account for a fact; it differs from theory in having no other evidence of its truth than that it affords a satisfactory explanation of phenomena.

IGNITION; from *ignis*, a fire; the state of being kindled, or more generally, the state of being heated to redness or incandescence.

INCANDESCENT from *incandesco*, to grow white; glowing with heat.

INCORPORATION; the mixing of different ingredients in one.

INCIPIENT; just beginning.

INFLAMMABLE, from *in* and *flamma*, a flame; capable of burning with a flame.

IMPINGE, from *impingo*, to strike against; to clash against.

ISOMERISM; substances which consist of the same elements, in the same proportions, and yet differ in their physical and chemical properties, are called *isomeric*.

LABORATORY; a room where operations and experiments in Chemistry, Pharmacy, Pyrotechny, &c., are performed.

LATENT; hidden, concealed.

LIME; a calcareous earth; an oxide of calcium, produced from chalk, shells, and certain stones, by expelling from them the carbonic acid, by means of strong heat in a furnace.

LIQUEFACTION; conversion of a solid into a liquid, by the agency of heat.

MANIPULATIONS; in *Chemistry*, the operation of preparing substances for experiments; in *Pharmacy*, the preparation of drugs; in *mining*, the manner of digging ores; in *general*, the performing of any work by hand.

MAGNESIA; an oxide of the metal magnesium; a soft white powder, without taste or odor.

MASS, -IVE; the quantity of matter in a body which is in proportion to its weight.

MATHEMATICS; the science which treats of quantity, and its applications to substance, time and space.

MAXIMUM, from *maximus*, greatest; the greatest value of a variable quantity.

MERCURY; a bluish white liquid metal, sometimes called quicksilver.

MINIMUM, from *minimus*, least; the least value of a variable quantity.

MINERAL COAL; vide page 30.

MOLECULES, -AR; the infinitely small material particles of which bodies are conceived to be made up.

MOMENTUM, from *moveo* to move; the product of the numbers which represent the quantity of matter and the velocity of a body is called momentum.

MULTIPLE; a quantity is said to be a multiple of another, when it contains that other quantity a certain number of times without a remainder.

NITROGEN; vide page 64.

ORGANISM; an organic structure, embracing the organs of motion, the organs of sensation, &c., &c.

OSCILLATE, from *oscillo*, to swing; a motion to and fro.

OXYGEN; vide page 60.

PEAT; vide page 37.

PETROLEUM; vide page 44.

PHENOMENON; an appearance; whatever is discovered to exist by observation or experiment.

PHLOGISTON; a rare ethereal substance once supposed to form a constituent part of all combustible bodies.

PHOSPHORUS; vide page 65.

PHOSPHORIC ACID; a white solid compound of one equivalent of phosphorus and three of oxygen.

PLATINUM; one of the heaviest of the metals, of the color of silver, discovered in Peru, by Charles Wood, in 1741.

POTASSIUM; a silver white metal, lighter than water, and possessing a powerful attraction for oxygen.

POTASH; the name given to a vegetable fixed alkali, which is obtained from the ashes of plants, by lixiviation, and evaporization.

PROPERTIES; the peculiar qualities of a thing.

PRODUCT, from *pro* from, and *duco*, to lead; anything formed from the elements of another by an operation.

QUICKLIME; a protoxide of calcium, obtained from carbonates of lime, as marble, shells, commonly known as *lime*, and used for making mortar and cements.

RETORT; a spherical vessel, with a long bent neck, to which a receiver may be fitted, used in distillation, &c.

RIGIDITY, from *rigiditas*, stiffness; the quality of resisting change of form.
SALT; in chemistry, a salt is a body composed of an acid and a base.
SALINE; partaking of the qualities of salt.
SHALE; a fine grained rock, having a slaty structure.
SILICIA; one of the names of silicic acid, which is composed of one equivalent of silicon and three of oxygen.
SPHAGNUM; a botanical term given to several species of mosses, which are remarkable for the whitish color of their leaves.
THEORY; an explanation of phenomena; it is founded upon inferences drawn from principles, which have been established on independent evidence.
VAPOR; an elastic fluid, rendered aeriform by heat, and capable of being brought back to the liquid or solid state by cold.
VAPORIZATION; the artificial formation of vapor.
VIBRATION, from *vibro* to brandish; the regular reciprocating motion of a body.
VOLATILE; capable of passing easily into the aeriform state.
VOLUME; the apparent space occupied by a body.

ERRATA.

PAGE 7, fourteenth line from the top, for "paralized" read *paralyzed.*
" 29, eighth line from the top, for "Acer Rubin" read *Acer Rubrum.*
" 32, eleventh line from the top, for "seventy" read *ninety.*
" 42, twenty-first line from the top, for "dry" read *dig.*
" 47, eleventh line from the top, for "forest" read *fruit.*
" 56, eighth line from the top, for "illustrates" read *illustrate.*
" 60, first line, insert *all* between the words "of" and "the".
" 64, fourteenth line from the top, for "oxygen" read *hydrogen.*
" 78, twenty-second line from the top, for "formed" read *burned.*
" 83, fifth line from the bottom for "Fave" read *Farve.*
" 89, twenty-fifth line from the top, for "measures" read *mixtures.*
" 110, sixteenth line from the bottom, for "carbonic acid" read *carbonic oxide.*
" 121, ninth line from the bottom, for one hundred and "twenty" atoms read one hundred and twenty-*eight* atoms.
" 136, thirteenth line from the top, for "for" read *by.*
" 143, fourth line from the bottom, for "pillows" read *pillars.*
" 151, second line from the bottom, for "Iron Discovery Company" read *Discovery Iron Company.*

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